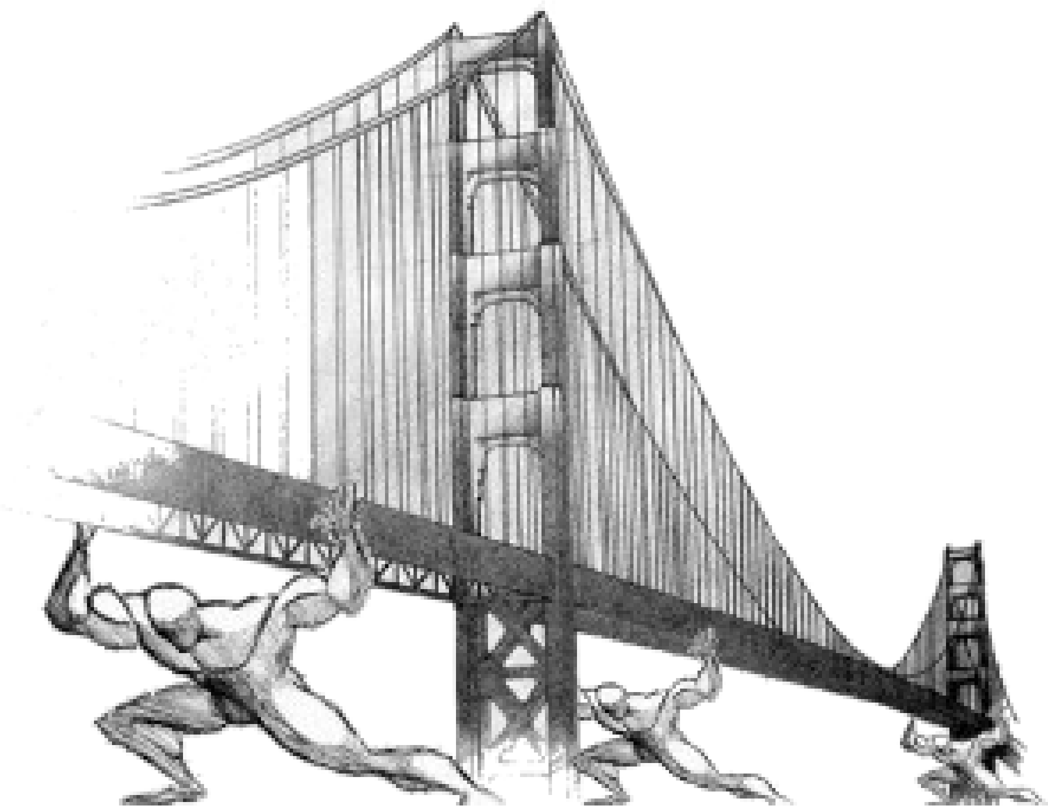
Real-time Bridge Monitoring

Guide to Inputs Conversion & Formulas calculation



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1 Type of Inputs

here are three inputs:

- *analog*********.txt* → in this txt file there are the values measured by the *Anemometer* and the *Hydrometer*
- *sonar**********.txt* → in this file there are the values measured by the *Echo Sonar*
- *Modean[Mantova]********.jpg* → there are the pictures taken by the two camera

How to interpret the ID/timestamp of a file

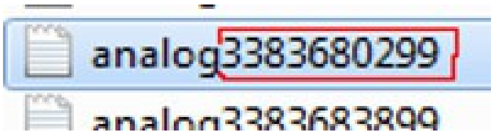
analog******.txt***
sonar*******.txt***

For this two kind of files the ID represents the Labview encoding and corresponds at the number of seconds that have elapsed sing 1th January 1904, without time zone so on the meridian of Greenwich (and at the same way for the timestamp of the all values in the file)
http://www.ni.com/white-paper/7900/en/

(there are 2 file (.xlsx & .ods) on GitHub [DSD/Data Source] that do this conversion automatically, just insert the number of seconds in the cell)

Example

File: analog3383680299.txt



(fig. 1)

s = 3383680299 ← fig. 1
m=(3383680299 / 60) = 56394671
h = (56394671 / 60) = 939911
d = (939911 / 24) = 39162
y = (39162 / 365) = 107

*rest of days = d - (y*365)=107*
*rest of hours = h - (d*24)=23*
*rest of minutes = m - (h*60)=11*
*rest of seconds = s – (m*60)=39*

The rest of days is 107, and it's corresponds at the month of April because 107 is between the sum of the days till March(that is 90) and the sum of days till April (that is 120). So mean that 107 days remaining corresponds at the month of April, the 4th.

How many days in April? Easily April begin after 90days so 107-90=17days elapsed.

Ok, here we are:

	Day 0	+	results	
y =	1904	+	107y	= 2011
m=	0	+	04m	= 04
d =	0	+	17d	= 17

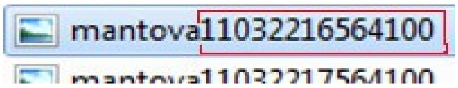
h = 00 + 23 = 23 h
m= 00 + 11 = 11 m
s = 00 + 39 = 39 s

*At the end we have converted **3383680299 → 2011/04/17 at 23:11:39** on meridian of Greenwich, so for Italy, Sweden and Croatia time (UTC+1) just add +1h at the time to have to correct one.*

Modean[Mantova]*****.jpg***	For the pictures the ID represents the exact date and time when the picture is taken

<u>Example</u>

File: mantova<u>11032216564100</u>.jpg



(fig. 2)

(fig. 3)

As you can see in fig. 3 this picture is taken on 22/03/2011 (DD/MM/YYYY) at 16:56:40 (hh:mm:ss)

So this information are used to build the timestamp of the file, in this way:

Y = 2011 → 11 take only the last two number of the year
M= 03
D = 22

h = 16
m= 56
s = 40

concatenating all these numbers we obtain:
Y|M|D|h|m|s
110322165640

So if we compare this result and the file ID
110322165640 ← concatenation of values
11032216564100 ← timestamp of the file
is the same value except for the last two numbers that we can discard
As you can see, this file was saved just 1sec after the picture was taken.

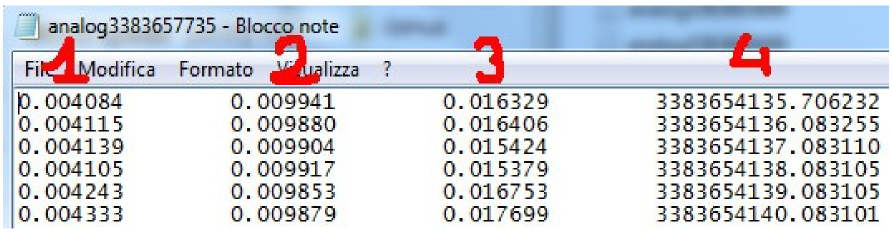
Concluding, we can extract the date&time when a picture was taken, just reading the file ID.

2 Content of Inputs

2.1 Analog files

The analog file contains 4 columns of values (*fig.4*):

1. **Wind speed** (unity measure mA)
2. **Distance between the Hydrometer and the level of water** (unity measure mA)
3. **Wind direction** (unity measure mA)
4. **Timestamp of the detection of the sample** (Labview encode → see before)[*decimals can be dropped]*


analog3383657735 - Blocco note
File Modifica Formato Visualizza ?

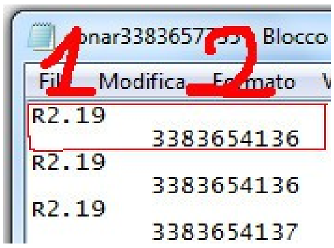
1	2	3	4
0.004084	0.009941	0.016329	3383654135.706232
0.004115	0.009880	0.016406	3383654136.083255
0.004139	0.009904	0.015424	3383654137.083110
0.004105	0.009917	0.015379	3383654138.083105
0.004243	0.009853	0.016753	3383654139.083105
0.004333	0.009879	0.017699	3383654140.083101

(fig. 4)

2.2 Echo Sonar files

The sonar file contains 2 columns of values, offset of a line (*fig.5*):

1. **Distance between the sonar and the bottom of the river** (unity measure meters)
2. **Timestamp of the detection of the sample** (Labview encode → see before)

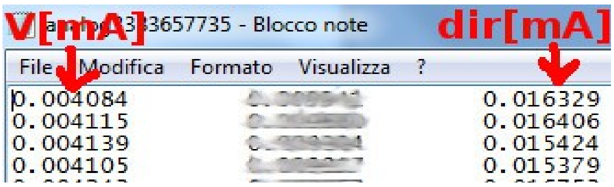


(fig.5)

3 Conversion operations on inputs

Every hour the system receives a packet in which there are an analog file, a sonar file both with 3600 values and two images, one for camera. All these values are to be converted from the parser into the db, in the table of *Raw_data(1sec)*. Each values has to fill one row of the table.

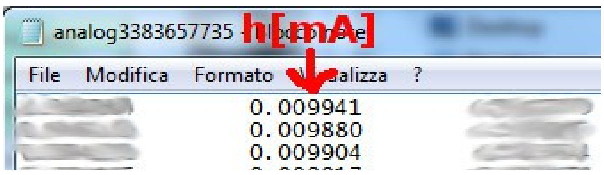
3.1 Anemometer



(fig.6)

- Speed → $V[m/s] = (((V[mA] * 1000) - 4) * 3{,}75)$
- Direction → $dir[°] = (((dir[mA] * 1000) - 4) * 22{,}5)$

3.2 Hydrometer



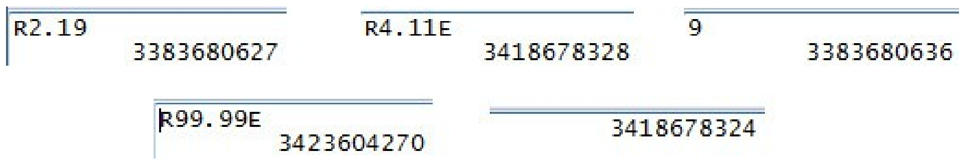
(fig.7)

- Distance hydrometer-water → $h[m] = 20 + (((h[mA] * 1000) - 4) * (-1{,}25))$
- Water height → $h_{water}[m] = 29{,}86 - h[m]$

3.3 Sonar

For the sonar is a little bit more complicated because the sonar can produces five different kind of data.

1) **Correct data** → **Rxx.xx** *(can exist even one decimal)*
2) **Uncertain data** → **Rxx.xxE** *(can exist even one decimal)*
3) **Wrong data** → **xx.xx** *(can exist even one decimal)*
4) **Sonar out of water** → **R99.99E**
5) **Error** → **E1 or missing data**



(fig.8)

The generic xx.xx is the distance in ***meter*** between the sonar and the height of the bottom.

- Height of the bottom → $h_{bottom}[m] = 12{,}3 - xx.xx[m]$

Data that are of type ① and ② can be convert in a real height; for the other types this conversion is not possible but is necessary to store these information anyway, to compute some statistics that will explain later.

4 What kind the calculations are there to do?

To aggregate data for 10 minutes we have to manage 600 data as a single sample to calculate the needed information.

4.1 Anemometer (10min)

- [ANE1] mean wind speed
- [ANE2] maximum wind speed in the 10 minutes
- [ANE3] mean wind direction
- [ANE4] direction of the maximum wind speed in the 10 minutes

4.2 Hydrometer (10min)

- [IDRO1] mean water depth/water height

- [IDRO2] variance of the sample

4.3 Echo Sonar (10min)

- [SONAR1] mean value of the height of the bottom (only with data of type ① + ②)
- [SONAR2] variance of the sample (only with data of type ① + ②)
- [SONAR3] % of data of type "① + ②" used compared to the 600 elements of the sample
- [SONAR4] % of data of type "③" there are in the sample
- [SONAR5] % of data of type "④" there are in the sample
- [SONAR6] % of data of type "⑤" there are in the sample
- [SONAR7] % of data of type "②" there are, considering as sample the "① + ②" set of data (so not all the 600 data)

4.4 Images

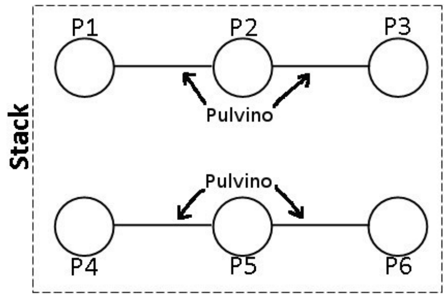
The images don't need any kind of elaboration, they have only to be displayed.

5 Calculation of Forcing

For the most of the formulas, is needed the use of parameters; these parameters are in a db table that only who have a high level of authorization can change. The change of parameters causes the re-elaboration of the all data in the grouped tables (customers know it and accept it).

5.1 Stack / Cell compositions

The bridge is supported by various stacks/cells (call as you want, we have to choose and agree on one word) and each stack is composed by two line of three pylons connected together by a "*pulvino*" (fig. 9).



(fig.9)

The system has to calculate the forces acting on the stack and after, if is possible, has to divide these forces on the two lines of the stack and divide again on the three pylons of each line.

5.2 Push of the wind

The push of the wind is divided in two components:

- S_{Vplank}: is the push of wind on the planking.
- S_{Vtraf}: is the push of wind on the traffic.

Because the traffic is not monitored, we have to use a combinations of possible traffic scenarios; In this model were modeled three scenarios, named A1, A2 and A3.

Effective speed

Before start to calculate the push of the wind on the whole bridge system, we must consider the real relevant value of the wind speed and not the general one. Is defined ***effective speed ($V_{EFFwind}$)*** *the wind component orthogonal to the bridge* and to calculate it are needed:

- Measured wind speed → [ANE2]
- Measured wind direction → [ANE4]
- Planimetric inclination of the bridge from the north → α (parameter)

$$V_{EFFwind} = [ANE2] * \sin([ANE4] + \alpha)$$

Push of the wind on the planking

For calculate this value are needed these information:

- "Drag planking" coefficient → C_{Dwi} (parameter)
- Air density → ρ (parameter)
- Planking area → A_{PLANK} (parameter)
- Effective wind speed → $V_{EFFwind}$ (see previous point)

$$S_{Vplank} = \frac{1}{2} * C_{Dwi} * \rho_{air} * A_{plank} * V^2_{EFFwind}$$

Push of the wind on the traffic

For calculate this variable we must consider the three possible traffic scenarios, and also are needed:

- "Drag traffic" coefficient → C_{Dwi} (the same of previous point)
- Air density → ρ_{air} (the same of previous point)
- Surface of traffic → A_{TRAF} (parameter)
- Aerial reduction coefficient → β_1 or β_2 (parameters)
- Effective wind speed → $V_{EFFwind}$ (see previous point)

For traffic combination A1:

$$S_{V(A1\ \ traf)} = \frac{1}{2} * C_{Dwi} * \rho_{air} * \left(\beta_1 * A_{traf}\right) * V^2_{EFFwind}$$

For traffic combination A2 (the same of A1):

$$S_{V(A2\ \ traf)} = \frac{1}{2} * C_{Dwi} * \rho_{air} * \left(\beta_1 * A_{traf}\right) * V^2_{EFFwind}$$

For traffic combination A3:

$$S_{V(A1\ \ traf)} = \frac{1}{2} * C_{Dwi} * \rho_{air} * \left(\beta_2 * A_{traf}\right) * V^2_{EFFwind}$$

5.3 Hydrodynamic thrust (on the whole stack)

The water pressure on the stack depends on the presence or not of debris on the stack basement

As the same way of the wind, will be calculate all the thrust and then choose at a later which consider.

Water speed

The hydrometer measures the height of the water, then we have to find a relation between the height of water and the water speed. To do this are needed:

- Scale of flow rates: correlates univocally the water height (h_{water} → [IDRO1]) and the flow rate (Q).
- Bidimensional analysis: allow to know for some flow rate value (Q) the relative value of water speed (V_{water})

Scale of flow rates

The following table show the relation between the flow rate (Q) and the water height (h_{water}). Depending on the value of h_{water} the parameters a_i, b_i and c_i changes.

- a_1, b_1, c_1 (parameters) for h_{water} < 17m
- a_2, b_2, c_2 (parameters) for 17m < h_{water} < 22m
- a_3, b_3, c_3 (parameters) for 22m < h_{water} < $h_{MAXwater}$

Scale of estimate flow rates with fixed section				
Parameters	[IDRO1] < 17m	17m <[IDRO1]< 22m	22m < [IDRO1] < $h_{MAXwater}$	$h_{MAXwater}$ = 25,3m
a_i	46	60	96	96
b_i	-902	-1350	-2800	-2800
c_i	4658	8000	22500	22500

$$Q = a_i * h_{water}^2 + b_i * h_{water} + c_i$$

if h_{water} > $h_{MAXwater}$ the river has overflowed.

2D Analysis

The relation between the flow rate of water and its speed are in the following table. Depending on the flow rate of water, you can identify the range and interpolate linearly to get the speed of water.

$$V_{water} = a * h_{water}^3 + b * h_{water}^2 + c * h_{water}$$

2D analysis – fixed bottom		
h_{water} [m]	Q [m³/s]	V_{water} [m/s]
3	510	0,24
10,5	5400	2,73
14	10000	3,54

N.B.: the parameters ***a,b*** and ***c*** are different from the parameters a_i, b_i and c_i

Water Thrust

To calculate the water thrust are needed these information:

- "Drag planking" coefficient → C_{Dwa} (different parameter from that of the wind, see below)
- Water density → ρ (parameter)
- Stack area → A_{stack}
- Water speed → V_{water} (see point before)

The "Drag planking" coefficient depends on the presence (D=1) or not (D=0) of debris on the stack base. So the Drag Planking coefficient is splited in:

- "Drag planking" coefficient (D=0) → C_{D0wa} (parameter)
- "Drag planking" coefficient (D=1) → C_{D1wa} (parameter)

The area of the stack invested by the flow of water depends on three factors:

- Presence (D=1) or not (D=0) of debris on the stack basement
- Height of the water → [IDRO1]
- Height of the bottom of the river –> [SONAR1]
- Shape of the stack; with presence of debris the shape of the stack changes, because the debris offer a greater surface on which the water can push.

The area of the stack is calculated using always the same formula, but depending on the scenario the coefficients involved change.

$$A_s = B_s * h_s$$

The h_s is calculated independently by the presence or not of debris:

- [SONAR1] < bottom_ref → **h_s = [IDRO2] - bottom_ref**
- [SONAR1] > bottom_ref → **h_s = [IDRO2] – [SONAR1]**

The *bottom_ref* is a parameter.

The B_s, depends instead on the presence or not of debris:

- D=0 → **$B_s = B_{s0} = c$**
- D=1 → **$B_s = B_{s1} = 2*D_{pylon}$**

c and D_{pile} are parameters

At the end we have this formulas:

(D = 0)	(D = 1)
$A_s = B_{s0} * h_s$ $S_{water} = \frac{1}{2} * C_{D0} * \rho_{water} * A_s * V^2_{water}$	$A_s = B_{s1} * h_s$ $S_{water} = \frac{1}{2} * C_{D1} * \rho_{water} * (A_s * \beta_A) * V^2_{water}$

5.4 Weight of the structure (o the whole stack)

In this case we have to calculate the weight of the stack and the portion of palking which is competence of the stack. Most of the weight that will be considered are constant, the only variable is related about the portion of the stack exposed, so that portion that is above the height of bottom of the river measured as [SONAR1].

To calculate this value, are needed these information:

- Load on the stack → P_P (parameter)
- Weight of pulvino → P_{pu} (parameter)
- Weight of trunk pylon → P_{tp} (parameter)
- Weight of the beam → P_b (parameter)
- Weight per meter of the single pylon → P_{py} (parameter)
- Height of the beam → h_{beam} (parametro)
- Height of stack portion exposed → to be evaluated with [SONAR1]

$$PP_{structure} = P_P + [(2 * P_{pu} + 6 * P_{tp} + 2 * P_b) + 6 * (P_{py} * (h_{beam} - [SONAR1]))]$$

5.5 Shifting weights / Mobile loads (traffic)

As said before in point 5.2, the traffic is not monitored so we have to use combinations of load, to suite the common possible scenarios. In this case we have 3 combinations that are A1, A2 and A3. At each combination was assigned a different contribute in terms of forces.

- A1 → N(A1), Mxx(A1) and Myy(A1)
- A2 → N(A2), Mxx(A2) and Myy(A2)
- A3 → N(A3), Mxx(A3) and Myy(A3)

The load combinations generate three kind of different forces: N is a vertical load, Mxx is a moment on the x axes and Myy is a moment on the y axes. The direction of the axes will be define later.

5.6 Brake of vehicles

In presence of traffic, there is the possibility of hard brakes by the vehicles that induce additional forces on the planking.

- F_R → vehicles braking (parameter)

5.7 Final remark on the forcing

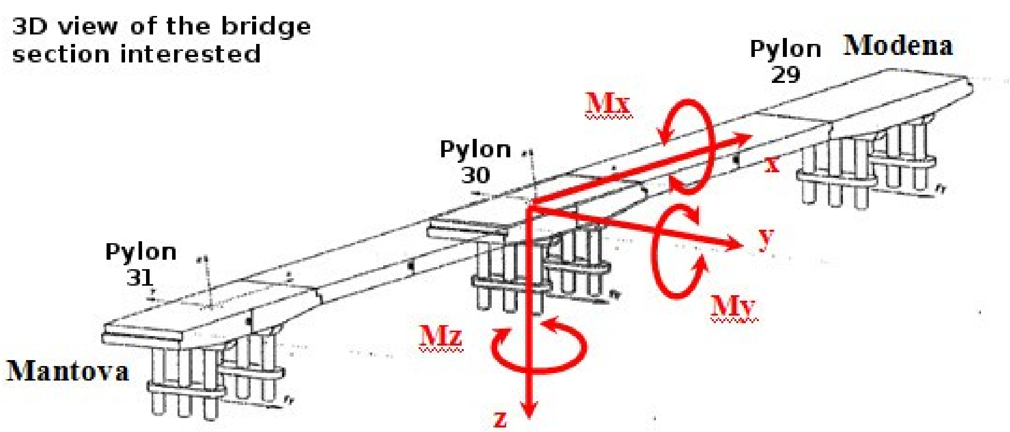
The forcing that act on the stack 30 are:

- Push of wind
- Hydrodynamic thrust
- Weight of the structure
- Shifting weight / Mobile loads
- Brake of vehicles

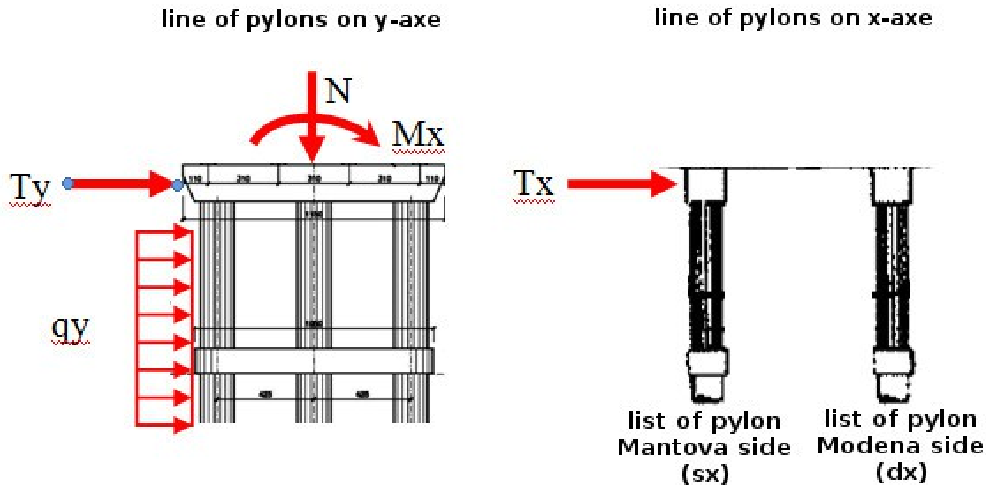
The descriptions and the formulas presented until here allow to value the generic force but say nothing about where this force is applied, if to the planking or directly to the stack or to both. The mainly purpose in to calculate the safety coefficient of the stack, all these generic forces must be transfer to the stack. During this "transferring" could born some new forces or some forces could transform in other forces and so on. At the end, all these forces and moments must be transferred also to the two lines of pylons that compose the single stack.

5.8 Reference system

Below will be present a schema of the reference system and the naming of forcing still transferred to the single line of pylon.



(fig. 10)



(fig. 11)

In these pictures, fig.10 and fig.11, are represented the generic forces acting on the stack, then each generic force contains the contributes of many forces. The following table explain how the contributes are distributed into the generic force.

Chassis	Forces				
Action	**Weight**	**Shifting weight**	**Brake**	**Wind**	**Water**
N	X	X	X		
Ty				X	
Tx			X		
qy					X
Mx		X		X	
My					
Mz					

(table 1)

To clarify this concept, for example think about the shifting weights. Before was said that the shifting weights, independently from the combination of traffic, exercise three kind of forces: N, Mxx and Myy. These three forces are applied to the planking and in their transfer to the single line of pylon, become N and Mx.

6 Forcing: from planking to the single line of pylons

Now we will take a look at each force acting on the bridge and how these forces are transferred from the planking to the single line of pylons.

The signs of the values are all related with the reference system described in the previous chapter (*fig.10 and fig.11)*.

6.1 Weight of the planking

The weight of the structure is composed by the weight of the planking that are on the stack (P_P) and the weight of the stack itself. For calculate how the weight of the structure is split on the two lines of pylons we consider only the weight of the planking on the stack. The own weight of the stack will be added at the end.

In the following table there are the value of the forces resulting from the analysis.

Description		Line of pylons Mantova side (sx)	Line of pylons Modena side (sx)	Unity measure
[N]	R1 = P_P / 2	+5355	+5355	kN
[N]	R2 = Mt/c_{span}	+1023	-1023	kN
[N]		***+6378***	***+4332***	***kN***

Mt ***,*** $\boldsymbol{c_{span}}$ are both parameters

6.2 Shifting loads (traffic combinations)

For the traffic combinations are reported the three final tables in which are described the decomposition of the forces in the three components as mentioned in the paragraph *5.5*.

Each combination will be duplicated in the next calculations due to the fact that the specific combination represents a double scenario because the traffic can be symmetrical (for example cars in left lane and trucks in right lane, but also the vice versa so trucks in left lane and cars in right lane). This stuff is represented by the possibility to the variables to change their sign.

ID	Combination	N (Wsl)	Mxx	Myy
		[kN]	[kNm]	[kNm]
A1	**1-a**	**4024**	**4368**	**3908**
Description		**Line of pylon Mantova side (sx)**	**Line of pylon Modena side (dx)**	**Unity Measure**
[N]	R1 = (N/2)	+ 2012	+ 2012	kN
[N]	R2 = (Myy/c_{span})	+ 411	- 411	kN
[Mx]	M1 = (Mxx/2)	± 2184	± 2184	kNm

ID	Combination	N (Wsl)	Mxx	Myy
		[kN]	[kNm]	[kNm]
A2	**1-b**	**3166**	**8077**	**3015**
Description		**Line of pylon Mantova side (sx)**	**Line of pylon Modena side (dx)**	**Unity Measure**
[N]	R1 = (N/2)	+ 1583	+ 1583	kN
[N]	R2 = (Myy/c_{span})	± 317	∓ 317	kN
[Mx]	M1 = (Mxx/2)	± 4038.5	± 4038.5	kNm

ID	Combination	N (Wsl)	Mxx	Myy
		[kN]	[kNm]	[kNm]
A3	**2-a**	**1979**	**2121**	**25756**
Description		**Line of pylon Mantova side (sx)**	**Line of pylon Modena side (dx)**	**Unity Measure**
[N]	R1 = (N/2)	+ 989.5	+ 989.5	kN
[N]	R2 = (Myy/c_{span})	± 2711	∓ 2711	kN
[Mx]	M1 = (Mxx/2)	± 1060.5	± 1060.5	kNm

6.3 Vehicle braking

At the same way of the shifting loads, we can't know the direction the brake, then we have report the values in the following table with the corresponding signs.

Description		Line of pylons Mantova side (sx)	Line of pylons Modena side (sx)	Unity measure
[Tx]	$T1 = F_R / 2$	± 103	± 103	kN
[N]	$R1 = F_R * n/c_{span}$	± 72	∓ 72	kN

6.4 Wind

For the wind are still valid the considerations made before on the direction. The only different is that the wind direction is a value measured by monitoring, so we can know if its contribution is positive or negative.

Description		Line of pylons Mantova side (sx)	Line of pylons Modena side (sx)	Unity measure
[Ty]	$Fv = (Sv / 2)$	± Fv	± Fv	kN
[Ty]	$Rav = (S_{Vplank} * r/c_{span})$	± Rav	∓ Rav	kN
[Mx]	$Mxv = [(S_{Vplank} * e_{plank} + S_{Vtraf} * e_{traf}) / 2]$	± Mxv	± Mxv	kNm

For the [Ty] the ***Sv*** is the sum of $S_{Vplank} + S_{Vtraf}$, *while* r, e_{plank} *and* e_{traf} are parameters.

6.5 Water

The water thrust acts only on the stack, since the planking is at a higher level of riverbank; that is to say that the water can never reach the planking, so this force don't need to be transferred to from the planking to the pylons. The only operation is to transform a concentrated force on a distributed load, and split it equally on the two lines of pylons. The values sign is defined because the water can flow only in one direction.

Description		Line of pylons Mantova side (sx)	Line of pylons Modena side (sx)	Unity measure
[qy]	$qy = (S_{WATER} / h_s) / 2$	+ qy	+ qy	kN/m

7 Load combinations on the stack

Since some forces are not monitored, is not possible to know their direction and then the verse of these forces, that depending on the situations can stabilize or destabilize the whole structure.

To define in each moment the maximum stress scenario, we have to define load combinations which enclose all the possible situations.

In this table is reported, for each force, its contribution to the four generic resultant forces.

	Line of pylons MANTOVA side (sx)					Line of pylons MODENA side (dx)				
	N	**Tx**	**Ty**	**qy**	**Mx**	**N**	**Tx**	**Ty**	**qy**	**Mx**
P_p	+R1 +R2	0	0	0	0	+R1 -R2	0	0	0	0
A110	+R1 +R2	0	0	0	+M1	+R1 -R2	0	0	0	+M1
A120	+R1 +R2	0	0	0	-M1	+R1 -R2	0	0	0	-M1
A210	+R1 +R2	0	0	0	+M1	+R1 -R2	0	0	0	+M1
A220	+R1 +R2	0	0	0	-M1	+R1 -R2	0	0	0	-M1
A311	+R1 +R2	0	0	0	+M1	+R1 -R2	0	0	0	+M1
A312	+R1 -R2	0	0	0	+M1	+R1 -R2	0	0	0	+M1
A321	+R1 +R2	0	0	0	-M1	+R1 -R2	0	0	0	-M1
A322	+R1 -R2	0	0	0	-M1	+R1 -R2	0	0	0	-M1
FR01	+R1	+T1	0	0	0	-R1	+T1	0	0	0
FR02	-R1	-T1	0	0	0	-R1	-T1	0	0	0
VT0	0	0	± (Fv0 + Rav)	0	± Mxv0	0	0	± (Fv0 - Rav)	0	± Mxv0
VT1A1	0	0	± (FvA1 + Rav)	0	± MxvA1	0	0	± (FvA1 - Rav)	0	± MxvA1
VT1A2	0	0	± (FvA2 + Rav)	0	± MxvA2	0	0	± (FvA2 - Rav)	0	± MxvA2
VT1A2	0	0	± (FvA3 + Rav)	0	± MxvA3	0	0	± (FvA3 - Rav)	0	± MxvA3
AQD0	0	0	0	qy	0	0	0	0	qy	0
AQD1	0	0	0	qy	0	0	0	0	qy	0

Notes:

In the combination VT0 the bridge is ideally closed, so there is no traffic. The Fv0 identify the component of the wind force that acts only on the planking and the same thing with for the Mxv0.

-VT0 : wind thrust without traffic on the bridge

-VT1Ax: wind thrust with traffic of type A1 or A2 or A3 on the bridge

-AQDx: water thrust in presence or not of debris.

7.1 Combination

comb_01A	→	Pp	AQD0	VT0		
comb_01B	→	Pp	AQD1	VT0		

comb_02A	→	Pp	AQD0	VT1A1	A110	FR01
comb_02B	→	Pp	AQD1	VT1A1	A110	FR01
comb_03A	→	Pp	AQD0	VT1A1	A110	FR02
comb_03B	→	Pp	AQD1	VT1A1	A110	FR02
comb_04A	→	Pp	AQD0	VT1A1	A120	FR01
comb_04B	→	Pp	AQD1	VT1A1	A120	FR01
comb_05A	→	Pp	AQD0	VT1A1	A120	FR02
comb_05B	→	Pp	AQD1	VT1A1	A120	FR02

comb_06A	→	Pp	AQD0	VT1A2	A210	FR01
comb_06B	→	Pp	AQD1	VT1A2	A210	FR01
Comb_07A	→	Pp	AQD0	VT1A2	A210	FR02
comb_07B	→	Pp	AQD1	VT1A2	A210	FR02
comb_08A	→	Pp	AQD0	VT1A2	A220	FR01
comb_08B	→	Pp	AQD1	VT1A2	A220	FR01
comb_09A	→	Pp	AQD0	VT1A2	A220	FR02
comb_09B	→	Pp	AQD1	VT1A2	A220	FR02

comb_10A	→	Pp	AQD0	VT1A3	A311	FR01
comb_10B	→	Pp	AQD1	VT1A3	A311	FR01
comb_11A	→	Pp	AQD0	VT1A3	A311	FR02
comb_11B	→	Pp	AQD1	VT1A3	A311	FR02
comb_12A	→	Pp	AQD0	VT1A3	A312	FR01
comb_12B	→	Pp	AQD1	VT1A3	A312	FR01
comb_13A	→	Pp	AQD0	VT1A3	A312	FR02
comb_13B	→	Pp	AQD1	VT1A3	A312	FR02
comb_14A	→	Pp	AQD0	VT1A3	A321	FR01
comb_14B	→	Pp	AQD1	VT1A3	A321	FR01
comb_15A	→	Pp	AQD0	VT1A3	A321	FR02
comb_15B	→	Pp	AQD1	VT1A3	A321	FR02
comb_16A	→	Pp	AQD0	VT1A3	A322	FR01
comb_16B	→	Pp	AQD1	VT1A3	A322	FR01
comb_17A	→	Pp	AQD0	VT1A3	A322	FR02
comb_17B	→	Pp	AQD1	VT1A3	A322	FR02

Each of these combinations will provide a set of values N, Tx, Ty, qy and Mx with their specific signs that identify the forces direction.

At each combinations must be add the weight of the stack because, as said before, was "ignored" in the calculations of the force due by the weight of the structure.

This mean that the generic resultant force N must be increased to a $\boldsymbol{N_{Ps}}$.

Defined

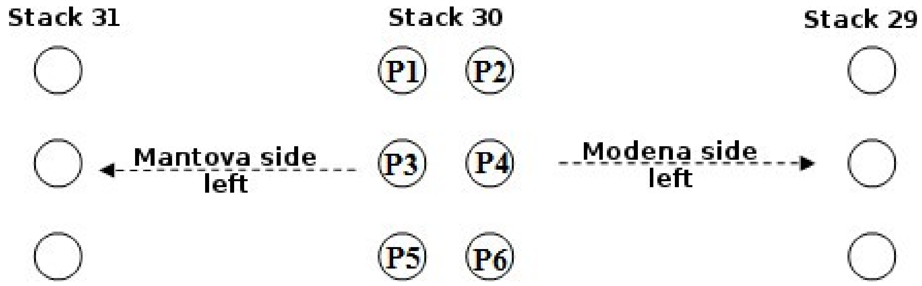
$$PP_s = [(2 * P_{pu} + 6 * P_{tp} + 2 * P_b) + 6 * (P_p * (h_{beam} - [SONAR1]))] \quad \rightarrow \quad N_{Ps} = + \frac{PP_s}{2}$$

Now, using the structural model is possible to determine the stresses in the six pylons and be able to choose the most stressed pylon, identifying the load combination that generates it.

8 Stress to the joints

Before provide the formulas that allow to determine the stresses at the bases of the six pylons that compose the stack n.30, is needed to introduce some information and schemes.

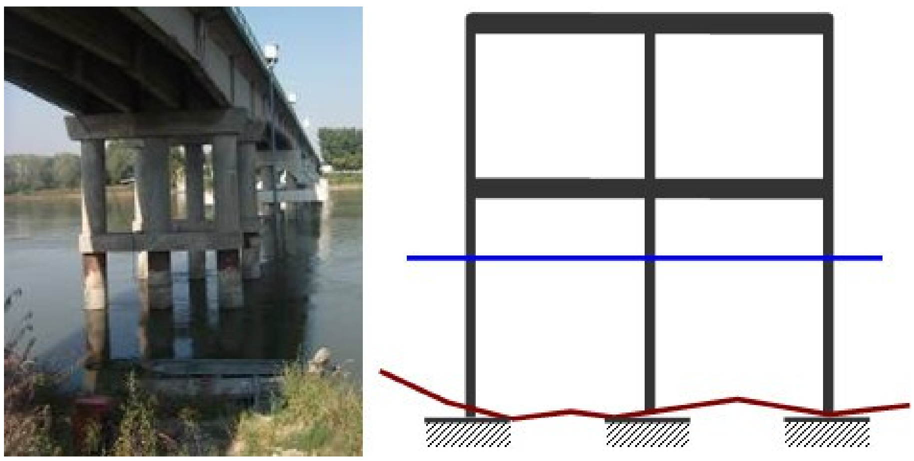
8.1 numbering of the individual pylons



(fig. 12)

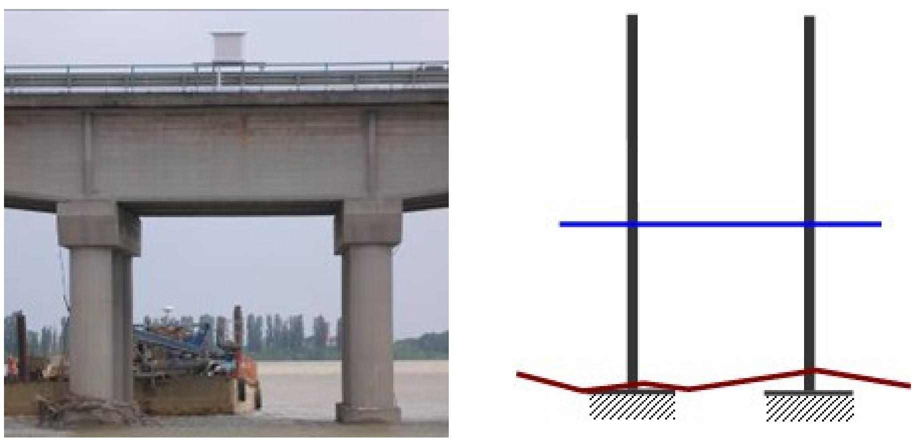
8.2 Introduction to the structural model

(y direction): flat frame



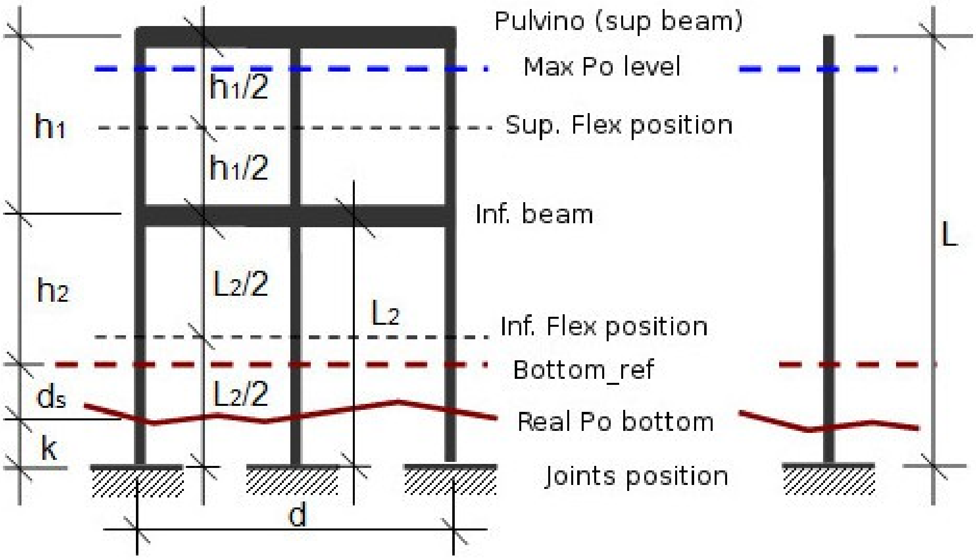
(fig. 13)

(x direction):



(fig. 14)

8.3 Geometry of the structural model (parameters from the parameters table)



(fig. 15)

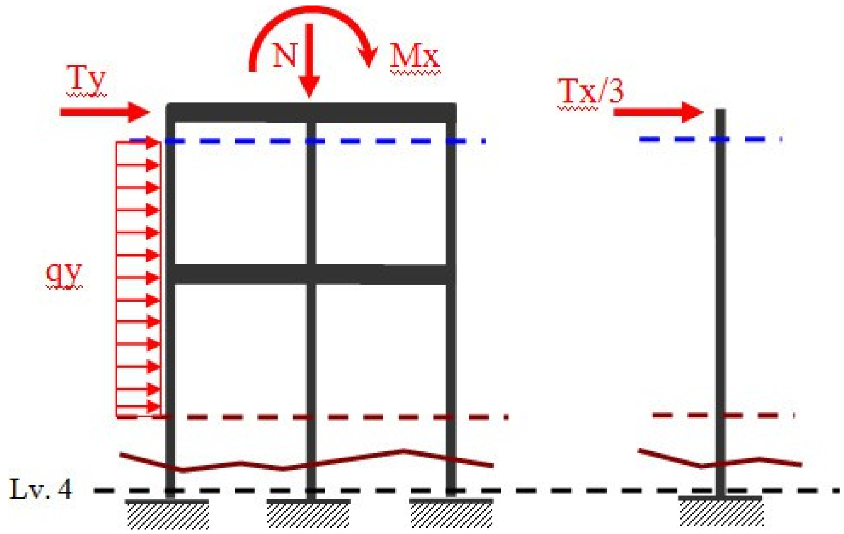
Distance	Value	Notes
L	variable	Depends by ds
L2	variable	Depends by ds
h1	7.30 [m]	Parameter
h2	7.50 [m]	Parameter
(h1)/2	3.65 [m]	Parameter
(L2)/2	variable	Depends by ds
ds	variable	Depends by the monitoring
d	8.5	Parameter (frame width)
k	0 [m]	Parameter (by hypothesis)

Notes:

The geometry provided in the pictures before, defined some distances that are present in the final formulas. All these parameters must be put into the parameters table.

The formulas reported below contain many parameters that up to day are set to zero (or to a default value) due to a lack of specific information.

8.4 Summary of kind of forces acting on the frame



(fig. 16)

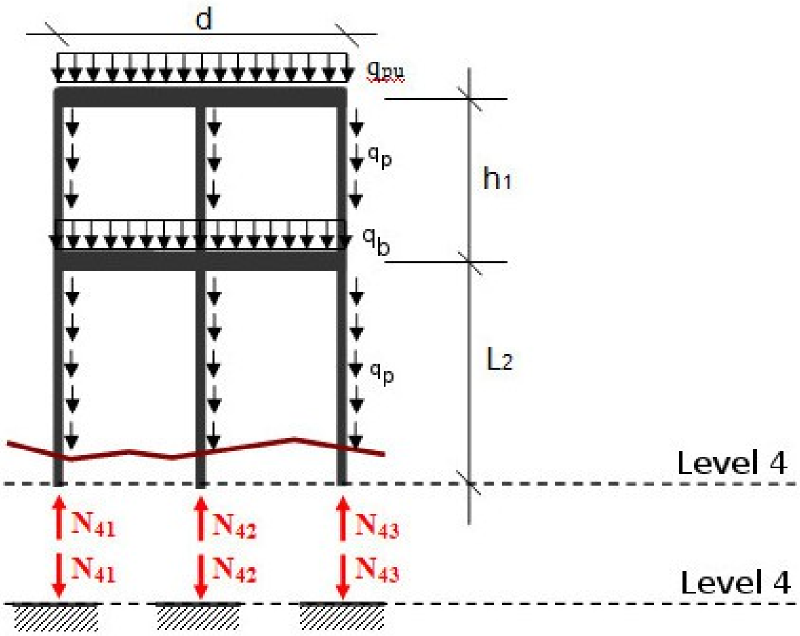
Notes:

… something that I don't understand xD ..

8.5 Structure weight

In the figure below are represented only the load external at the stack, so we can neglect the weight of the stack because is by own definition is not an external load on the stack.

The picture shows the weights of the frame split in pulvino weight (qpu), pylon weight (qp) and beam weight (qb). In the section at the base, naming "Level 4".

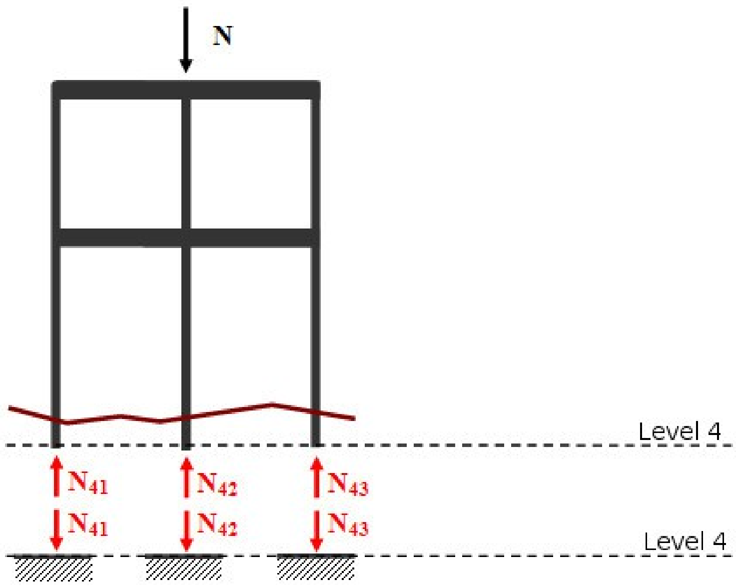


(fig. 17)

$$\boxed{N_{41} = N_{42} = N_{43} = \frac{(q_{pu} + q_b) * d}{3} + q_p * (h_1 + L_2)}$$

The weight of the truck stack (p_{ts})is equal to q_p*h1

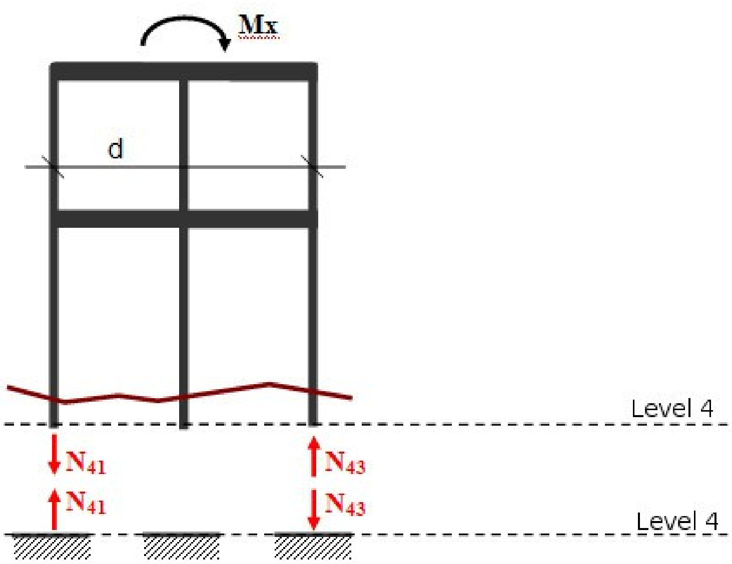
8.6 Vertical load N



(fig. 18)

$$\boxed{N_{41} = N_{42} = N_{43} = \frac{N}{3}}$$

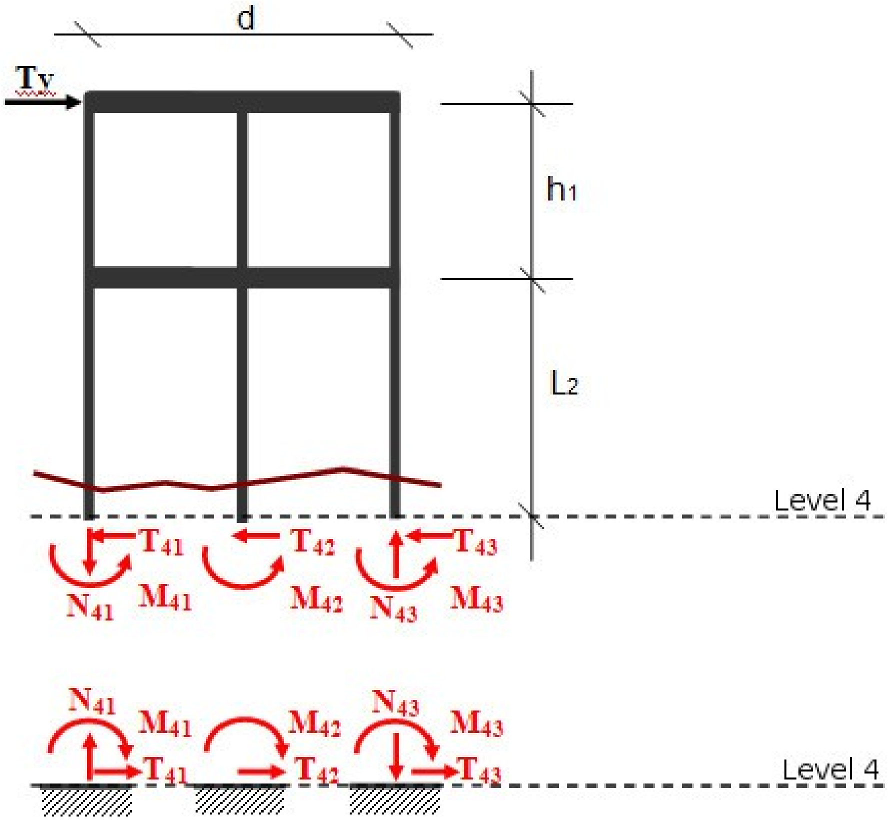
8.7 Bending moment



(fig. 19)

$$\boxed{N_{41} = -N_{43} = \frac{M_x}{d}} \qquad \boxed{N_{42} = 0}$$

8.8 Cutting force



(fig. 20)

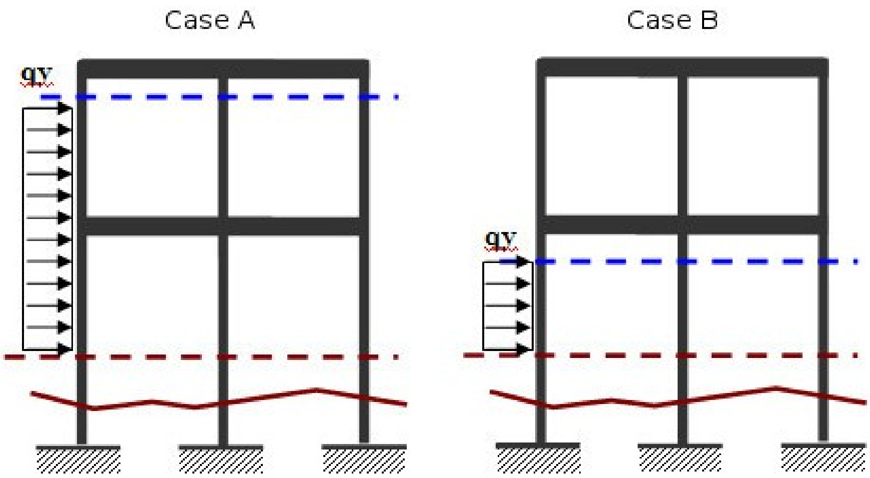
$$N_{41} = -N_{43} = \left[\frac{T_y}{d}\left(h_1 + \frac{L_2}{2}\right)\right]$$

$$T_{41} = T_{42} = T_{43} = \frac{T_y}{3}$$

$$M_{41} = M_{42} = M_{43} = \frac{T_y * L_2}{6}$$

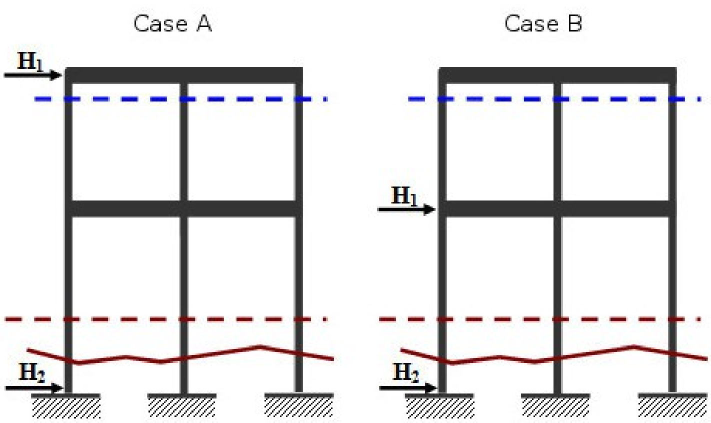
8.9 Distributed Load (qy)

This topic is not easy to discuss at the joints, because the area of interest is variable since depends on the level of the river. For simplicity are evaluated only two cases: case A in which the level of the river is higher than the inferior beam and case B in which the level of the river is lesser than the inferior beam, like in the figure below.



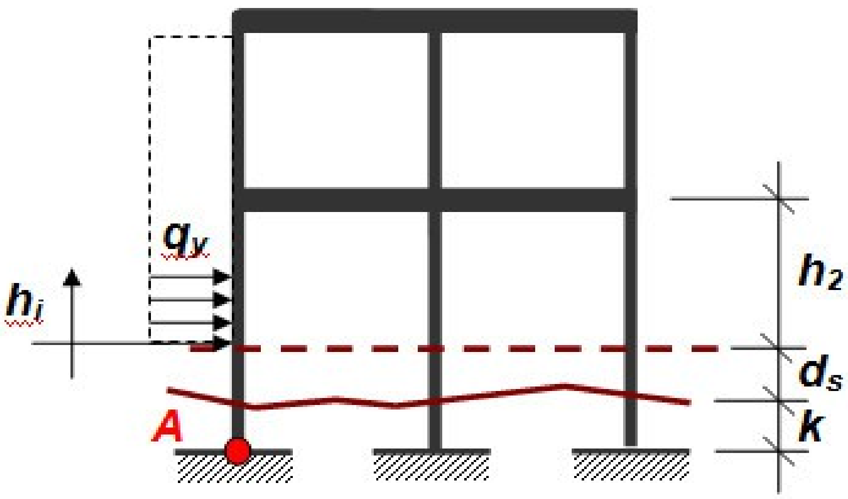
(fig. 21)

Later, is replaced the generic distributed load with a system of concentrated equivalent forces. For a better understanding, are reported the all steps to determine the equivalent concentrated forces.



(fig. 22)

Once determined the resulting H, its moment is balanced respect a joint, point A fig23, with the component H1 that is the only component that generates a moment; the other component H2 is obtained by difference.

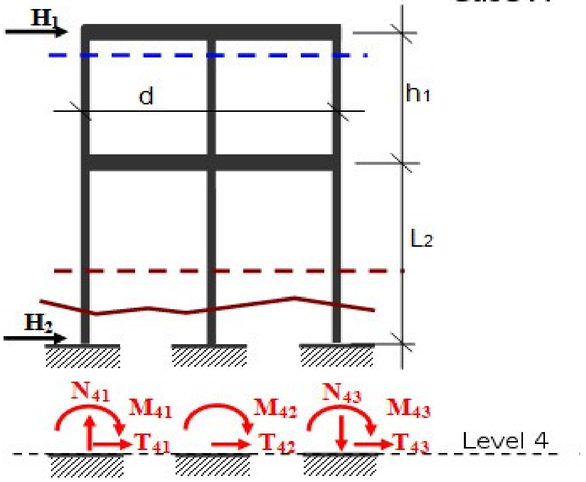


(fig. 23)

Case A $h_i >= h_2$	***Case B $h_i < h_2$***
Calculation of the resulting H	
$H = q_y * h_i$	$H = q_y * h_i$
Calculation of the moment of H, respect to point A	
$M_{(H)} = H * \left(\frac{h_i}{2} + d_s + k \right)$	$M_{(H)} = H * \left(\frac{h_i}{2} + d_s + k \right)$
Calculation of H1, equaling the moment of H	
$H_1 = \frac{M_{(H)}}{h_1 + L_2}$	$H_1 = \frac{M_{(H)}}{L_2}$
Calculation of H2 by difference	
$H_2 = H - H_1$	$H_2 = H - H_1$

Even if the concentrated forces for both configurations have the same encoding (H1 and H2), their values are different, since derive from a different distribution of q_y.

Case A



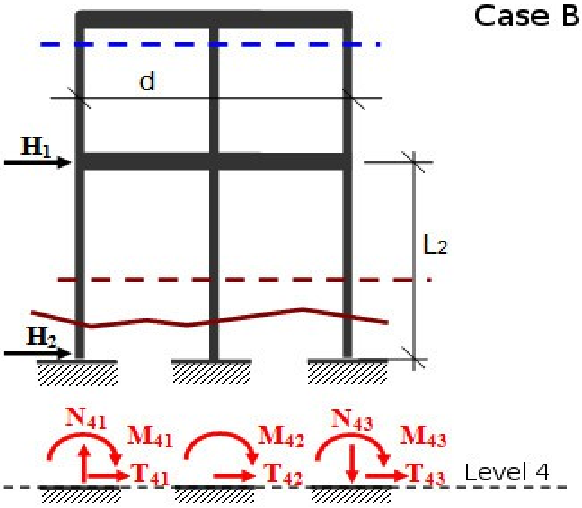
(fig. 24)

$$\boxed{N_{41} = -N_{43} = \left[\frac{H_1}{d}\left(h_1 + \frac{L_2}{2}\right)\right]}$$

$$\boxed{T_{41} = T_{42} = T_{43} = \frac{H_1 + H_2}{3}}$$

$$\boxed{M_{41} = M_{42} = M_{43} = \frac{H_1 \ L_2}{6}}$$

Case B



(fig. 25)

$$\boxed{N_{41} = -N_{43} = \frac{H_1 * L_2}{2\mathrm{d}}}$$

$$\boxed{T_{41} = T_{42} = T_{43} = \frac{H_1 + H_2}{3}}$$

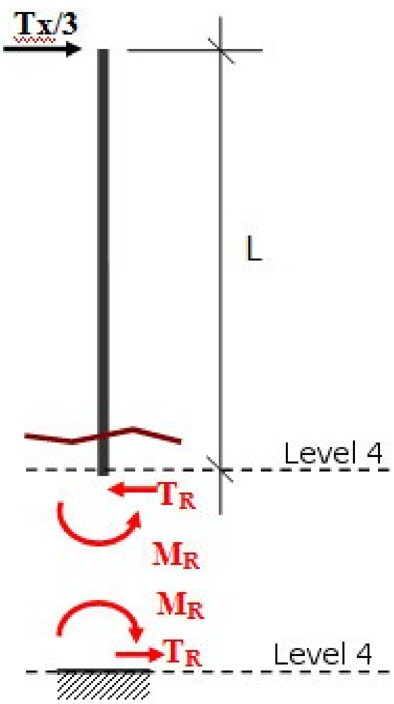
$$\boxed{M_{41} = M_{42} = M_{43} = \frac{H_1 \ L_2}{6}}$$

This note allow to define the case B as a particular case of case A: if the Po level was lower than the beam, the formula of the axial stress of case A should reset the h1 height. Next are identify the end formulas in their range of use.

	Case A (hi >= h2)	**Case B (hi < h2)**
N	$N_{41} = -N_{43} = \left[\frac{H_1}{d}\left(h_1 + \frac{L_2}{2}\right)\right]$	$N_{41} = -N_{43} = \frac{H_1 * L_2}{2\mathrm{d}}$
T	$T_{41} = T_{42} = T_{43} = \frac{H_1 + H_2}{3}$	
M	$M_{41} = M_{42} = M_{43} = \frac{H_1 \ L_2}{6}$	

8.10 Cutting force T_x

The chassis subject to a force Tx, has a structural behaves like a “shelf”. The figure below defines the stresses that this Tx force make on the joint. Remember that Tx/3 is the force that acts on the single pylon.



$$\boxed{T_R = \frac{T_x}{3}}$$

$$\boxed{M_R = \frac{T_x * L}{3}}$$

(fig. 26)

8.11 superposition of effects *(effects overlapping)*

The stresses that each force generates to the joints can be simply added, determining the total stresses. The representation of this process will be show separating the stresses to the joints and explaining this stress for each of the three pylons. To be general, the formulas will be refer to the three pylons of the generic line not with the encoding of page 19 (fig. 12) but with the simple encoding of 1, 2 and 3. So the formulas are valid for both of the lines of the stack. Moreover the generic stress will have a subscript that identify the direction (x or y) and the reference section, the number 4. In the following tables, from 2 to 6 are defined respectively the stresses to the joints: axial force N, cutting force Tx, cutting force Ty, bending moment Mx and bending moment My.

Axial stress N

	Pylon 1	Pylon 2	Pylon 3
P.P.	$N_4 = \frac{(q_{pu} + q_b) * d}{3} + q_{pylon} * L$	$N_4 = \frac{(q_{pu} + q_b) * d}{3} + q_{pylon} * L$	$N_4 = \frac{(q_{pu} + q_b) * d}{3} + q_{pylon} * L$
N	$N_4 = -\frac{N}{3}$	$N_4 = -\frac{N}{3}$	$N_4 = -\frac{N}{3}$
Ty	$N_4 = -\left[\frac{T_y}{d}\left(h_1 + \frac{L_2}{2}\right)\right]$		$N_4 = \left[\frac{T_y}{d}\left(h_1 + \frac{L_2}{2}\right)\right]$
Mc	$N_4 = -\frac{M_x}{3}$		$N_4 = \frac{M_x}{3}$
qy	$N_4 = -\left[\frac{H_1}{d}\left(h_1 + \frac{L_2}{2}\right)\right]$		$N_4 = \left[\frac{H_1}{d}\left(h_1 + \frac{L_2}{2}\right)\right]$
Tx			

Tab.2: contributions of singles forces to the axial stress N

Cutting force Tx

	Pylon 1	Pylon 2	Pylon 3
P.P.			
N			
Ty			
Mc			
qy			
Tx	$T_{x4} = \frac{Tx}{3}$	$T_{x4} = \frac{Tx}{3}$	$T_{x4} = \frac{Tx}{3}$

Tab.3: contributions of singles forces to the cutting action Tx

Cutting force Ty

	Pylon 1	Pylon 2	Pylon 3
P.P.			
N			
Ty	$T_{y4} = \frac{Ty}{3}$	$T_{y4} = \frac{Ty}{3}$	$T_{y4} = \frac{Ty}{3}$
Mc			
qy	$T_{y4} = \frac{q_y * h_i}{3}$	$T_{y4} = \frac{q_y * h_i}{3}$	$T_{y4} = \frac{q_y * h_i}{3}$
Tx			

Tab.4: contributions of singles forces to the cutting action Ty

Blending stress Mx

	Pylon 1	Pylon 2	Pylon 3
P.P.			
N			
Ty	$M_{x4} = \frac{T_y * L_2}{6}$	$M_{x4} = \frac{T_y * L_2}{6}$	$M_{x4} = \frac{T_y * L_2}{6}$
Mc			
qy	$M_{x4} = \frac{H_1 * L_2}{6}$	$M_{x4} = \frac{H_1 * L_2}{6}$	$M_{x4} = \frac{H_1 * L_2}{6}$
Tx			

Tab.5: contributions of singles forces to the stress Mx

Blending stress My

	Pylon 1	Pylon 2	Pylon 3
P.P.			
N			
Ty			
Mc			
qy			
Tx	$M_{y4} = \frac{T_x * L}{3}$	$M_{y4} = \frac{T_x * L}{3}$	$M_{y4} = \frac{T_x * L}{3}$

Tab.6: contributions of singles forces to the stress My

9 Verification of “Pressoflessione” *(buckling)*

<...”Pressoflessione” is the combination of compressive and bending stress. One of the possible English translation is “buckling” or “Carico in punta” in Italian....”

… coming soon...

10 Table of parameters

GEOMETRY OF THE STACK N.30			
D_{pylon}	1.5	m	Diameter of the pylon
c_{span}	9.5	m	Distance between two line of pylon
h_{beam}	17.5	m	Height of the lower beam
bottom_ref	10	m	Height of the reference of the bottom of the river
h1	7.3	m	Distance between the pulvino and the inferior beam
h2	7.5	m	Distance between the inferior beam and the bottom_ref
(h1)/2	3.65	m	Mean value of h1
k	0	m	Sinking of the joints over the ground
d	8.5	m	Width of the chassis
WIND THRUST			
α	6	°	Planimetric inclination of the bridge form the north
C_{Dwi}	2	-	“Drag planking” coefficient
ρ_{air}	1.2	Kg/m^3	Air density
A_{stack}	160	m^2	Planking area exposed to the wind pressure
A_{traf}	177	m^2	Surface of traffic exposed to the wind pressure
β_1	1	-	Coefficient of reduction for A1 and A2 traffic scenarios
β_2	0.5	-	Coefficient of reduction for A3 traffic scenario
r	2.25	m	-
e_{plank}	1.91	m	-
e_{traf}	3.41	m	-
HYDRODYNAMIC THRUST			
C_{D0wa}		-	“Drag planking” coefficient (D=0)
C_{D1wa}		-	“Drag planking” coefficient (D=1)
ρ_{water}		Kg/m^3	Water density
β_A		-	Area reduction for D=1
a		-	Coefficient for the relation $V_{water(}$[IDRO1])
b		-	Coefficient for the relation $V_{water(}$[IDRO1])
c		-	Coefficient for the relation $V_{water(}$[IDRO1])
h_{water1}	17	m	Height limit of the river for parameters a1,b1,c1
a1	46	-	Coefficient for Q(h) when [IDRO1] < h_{water1}
b1	-902	-	Coefficient for Q(h) when [IDRO1] < h_{water1}
c1	4658	-	Coefficient for Q(h) when [IDRO1] < h_{water1}

h_{water2}	22	m	Height limit of the river for parameters a2,b2,c2
a2	60	-	Coefficient for Q(h) when [IDRO1] < h_{water2}
b2	-1350	-	Coefficient for Q(h) when [IDRO1] < h_{water2}
c2	8000	-	Coefficient for Q(h) when [IDRO1] < h_{water2}
h_{max}	25.3	m	Max height level of river and limit for use parameter a3,b3,c3
a3	96		Coefficient for Q(h) when h_{water2} < [IDRO1] < h_{max}
b3	-2800		Coefficient for Q(h) when h_{water2} < [IDRO1] < hmax
c3	22500		Coefficient for Q(h) when h_{water2} < [IDRO1] < hmax
WEIGHT OF THE STACK			
Pp	10710	kN	Plank weight on the stack
Ppu	1680	kN	Weight of single pulvino
Ptp	1601	kN	Weight of the trunk of pylon
Pb	1007	kN	Weight of the single beam
Ppy	44	kN/m	Weight per meter of pylon
Mt	9720	kNm	Moment generated by asymmetry
SHIFTING WEIGHTS			
N(A1)	4024	kN	Axial load for load combination A1
Mxx(A1)	4368	kNm	Bending moment for load combination A1
Myy(A1)	3908	kNm	Bending moment for load combination A1
N(A2)	3116	kN	Axial load for load combination A2
Mxx(A2)	8077	kNm	Bending moment for load combination A2
Myy(A2)	3015	kNm	Bending moment for load combination A2
N(A3)	1979	kN	Axial load for load combination A3
Mxx(A3)	2121	kNm	Bending moment for load combination A3
Myy(A3)	25756	kNm	Bending moment for load combination A3
Vehicle braking			
F_r	206	kN	Value of the force due to the vehicle braking
n	3.3	m	“arm” for the vehicle braking moment