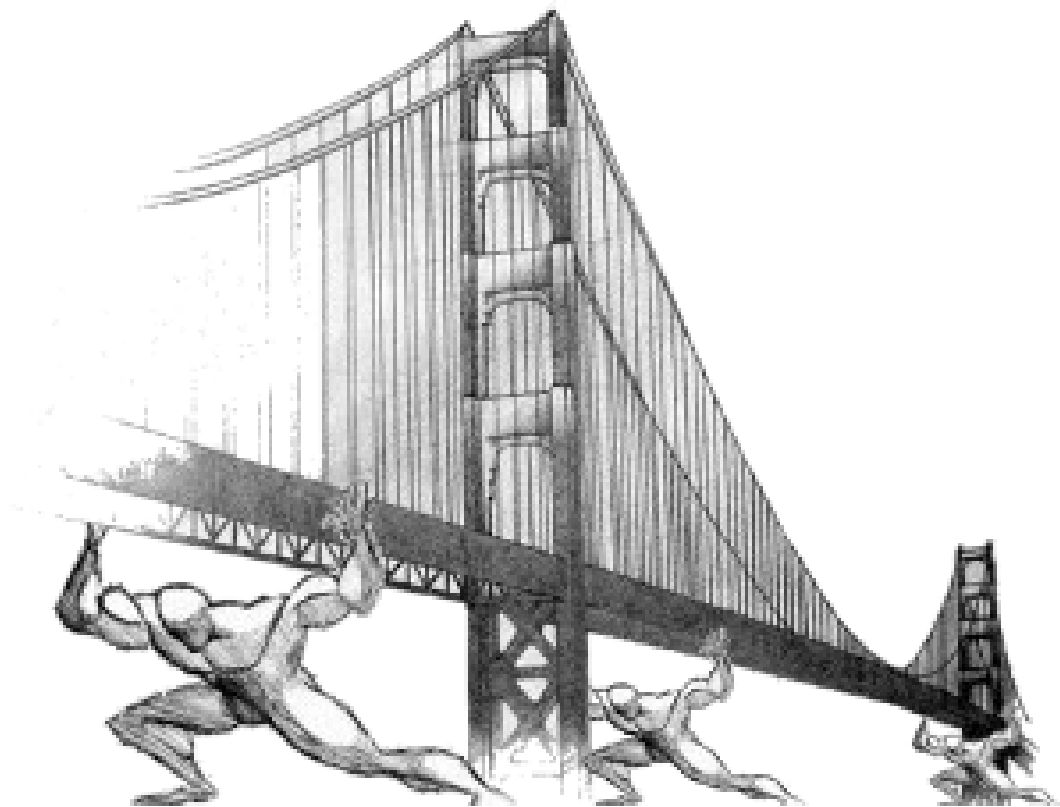


# Real-time Bridge Monitoring

*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*

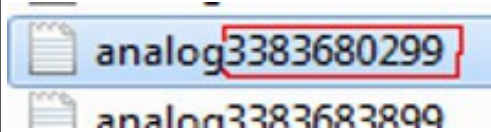
For this two kind of files the ID represents the Labview encoding and corresponds at the number of seconds that have elapsed sing 1th January 1904, without time zone so on the meridian of Greenwich (and at the same way for the timestamp of the all values in the file)

<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)

$s = 3383680299 \leftarrow \text{fig. 1}$

$m = (3383680299 / 60) = 56394671$

$h = (56394671 / 60) = 939911$

$d = (939911 / 24) = 39162$

$y = (39162 / 365) = 107$

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 4<sup>th</sup>.

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

Ok, here we are:

Day 0 + results

$y = 1904 + 107y = 2011$

$m = 0 + 04m = 04$

$d = 0 + 17d = 17$

$h = 00 + 23 = 23 \text{ h}$

$m = 00 + 11 = 11 \text{ m}$

$s = 00 + 39 = 39 \text{ s}$

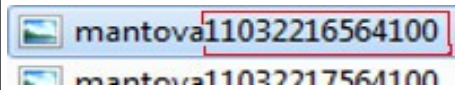
At the end we have converted **3383680299** → **2011/04/17 at 23:11:39** on meridian of Greenwich, so for Italy, Sweden and Croatia time (UTC+1) just add +1h at the time to have to correct one.

**Modean[Mantova]\*\*\*\*\*.jpg**

For the pictures the ID represents the exact date and time when the picture is taken

### Example

File: mantova11032216564100.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]

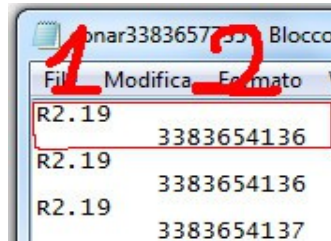
1	2	3	4
0.004084	0.009941	0.016329	3383654135.706232
0.004115	0.009880	0.016406	3383654136.083255
0.004139	0.009904	0.015424	3383654137.083110
0.004105	0.009917	0.015379	3383654138.083105
0.004243	0.009853	0.016753	3383654139.083105
0.004333	0.009879	0.017699	3383654140.083101

(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)



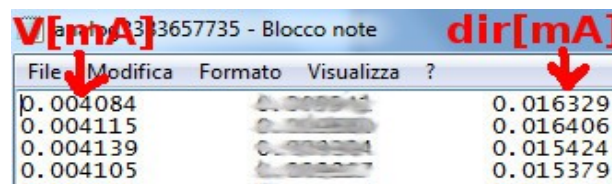
Timestamp	Distance
R2.19	3383654136
R2.19	3383654136
R2.19	3383654137

(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

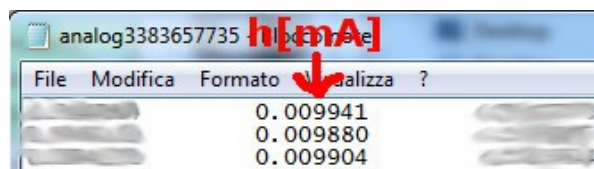


V[mA]	dir[mA]
0.004084	0.016329
0.004115	0.016406
0.004139	0.015424
0.004105	0.015379

(fig.6)

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

### 3.2. Hydrometer



h[mA]	h <sub>water</sub> [m]
0.009941	
0.009880	
0.009904	

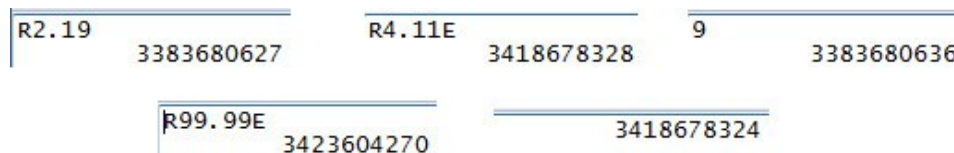
(fig.7)

- 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**

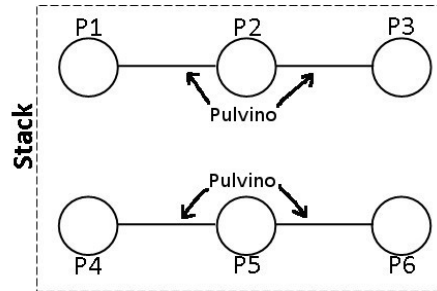
The images don't need any kind of elaboration, they have only to be displayed.

## 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 “pulgino” (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.

#### 5.2.1. 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  $\rightarrow [ANE2]$
- Measured wind direction  $\rightarrow [ANE4]$
- Planimetric inclination of the bridge from the north  $\rightarrow \alpha$  (parameter)

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



### 5.2.2. Push of the wind on the planking

For calculate this value are needed these information:

- “Drag planking” coefficient  $\rightarrow C_{Dwi}$  (parameter)
- Air density  $\rightarrow \rho$  (parameter)
- Planking area  $\rightarrow A_{PLANK}$  (parameter)
- Effective wind speed  $\rightarrow V_{EFFwind}$  (see previous point)

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

### 5.2.3. 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  $\rightarrow C_{Dwi}$  (the same of previous point)
- Air density  $\rightarrow \rho_{air}$  (the same of previous point)
- Surface of traffic  $\rightarrow A_{TRAF}$  (parameter)
- Aerial reduction coefficient  $\rightarrow \beta_1$  or  $\beta_2$  (parameters)
- Effective wind speed  $\rightarrow V_{EFFwind}$  (see previous point)

For traffic combination A1:

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

For traffic combination A2 (the same of A1):

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

For traffic combination A3:

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

### 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.

#### 5.3.1. 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 ( $h_{\text{water}} \rightarrow [\text{IDRO1}]$ ) and the flow rate ( $Q$ ).
- Bidimensional analysis: allow to know for some flow rate value ( $Q$ ) the relative value of water speed ( $V_{\text{water}}$ )

##### 5.3.1.1. Scale of flow rates

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

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

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

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

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

##### 5.3.1.2. 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.

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

2D analysis – fixed bottom		
$h_{\text{water}} [\text{m}]$	$Q [\text{m}^3/\text{s}]$	$V_{\text{water}} [\text{m/s}]$
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  $c_i$

### 5.3.2. Water Thrust

To calculate the water thrust are needed these information:

- “Drag planking” coefficient  $\rightarrow C_{Dwa}$  (different parameter from that of the wind, see below)
- Water density  $\rightarrow \rho$  (parameter)
- Stack area  $\rightarrow A_{stack}$
- Water speed  $\rightarrow V_{water}$  (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 splitted in:

- “Drag planking” coefficient ( $D=0$ )  $\rightarrow C_{D0wa}$  (parameter)
- “Drag planking” coefficient ( $D=1$ )  $\rightarrow C_{D1wa}$  (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  $\rightarrow [IDRO1]$
- Height of the bottom of the river  $\rightarrow [SONAR1]$
- 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:

- $[SONAR1] < \text{bottom\_ref} \rightarrow h_s = [IDRO2] - \text{bottom\_ref}$
- $[SONAR1] > \text{bottom\_ref} \rightarrow h_s = [IDRO2] - [SONAR1]$

The *bottom\_ref* is a parameter.

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

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

$c$  and  $D_{pylon}$  are parameters

At the end we have this formulas:

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

#### 5.4. Weight of the structure (of 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 →  $P_s$  (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 →  $P_p$  (parameter)
- Height of the beam →  $h_{beam}$  (parametro)
- Height of stack portion exposed → to be evaluated with [SONAR1]

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

#### 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.

- $F_R \rightarrow$  brake of vehicles (parameter)

## 5.7. Final remark on the forcing

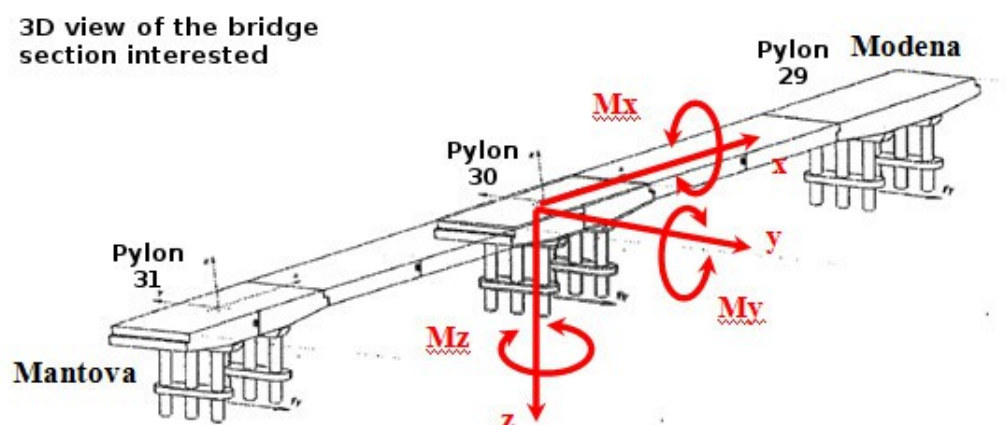
The forcing that act on the stack 30 are:

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

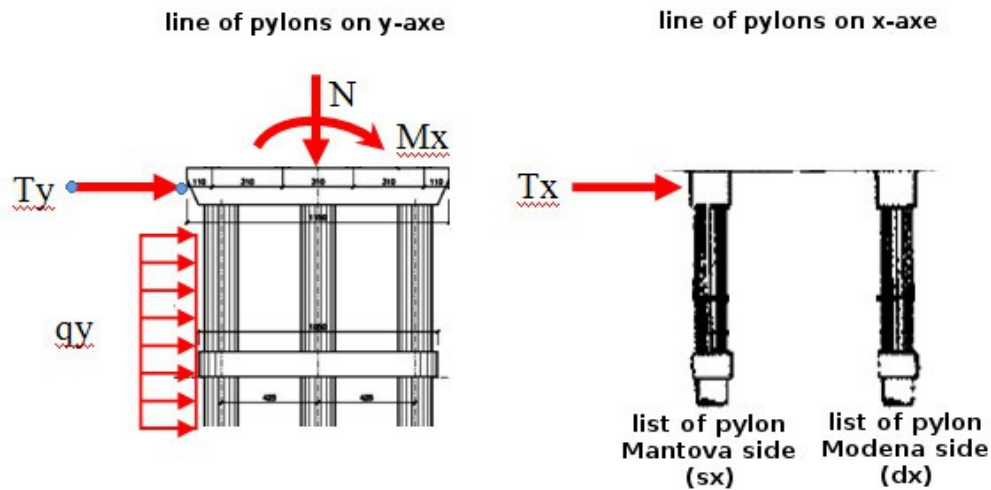
The descriptions and the formulas presented until here allow to value the generic force but say nothing about where this force is applied, if to the planking or directly to the stack or to both. The mainly purpose in to calculate the safety coefficient of the stack, all these generic forces must be transfer 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)



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					

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 pylon**

...coming soon...

## **7. Stress to the joints**

...coming soon...



## 8. Table of parameters

GEOMETRY OF THE STACK N.30			
$D_{\text{pylon}}$	1.5	m	Diameter of the pylon
$c$	9.5	m	Distance between two line of pylon
$h_{\text{beam}}$	17.5	m	Height of the lower beam
$\text{bottom\_ref}$	10	m	Height of the reference of the bottom of the river
WIND THRUST			
$\alpha$	6	°	Planimetric inclination of the bridge form the north
$C_{\text{Dwi}}$	2	-	"Drag planking" coefficient
$\rho_{\text{air}}$	1.2	Kg/m <sup>3</sup>	Air density
$A_{\text{stack}}$	160	m <sup>2</sup>	Planking area exposed to the wind pressure
$A_{\text{traf}}$	177	m <sup>2</sup>	Surface of traffic exposed to the wind pressure
$\beta_1$	1	-	Coefficient of reduction for A1 and A2 traffic scenarios
$\beta_2$	0.5	-	Coefficient of reduction for A3 traffic scenario
$r$	2.25	m	-
$e_{\text{imp}}$	1.91	m	-
$e_{\text{traf}}$	3.41	m	-
HYDRODYNAMIC THRUST			
$C_{\text{D0wa}}$		-	"Drag planking" coefficient (D=0)
$C_{\text{D1wa}}$		-	"Drag planking" coefficient (D=1)
$\rho_{\text{water}}$		Kg/m <sup>3</sup>	Water density
$\beta_A$		-	Area reduction for D=1
$a$		-	Coefficient for the relation $V_{\text{water}}([\text{IDRO1}])$
$b$		-	Coefficient for the relation $V_{\text{water}}([\text{IDRO1}])$
$c$		-	Coefficient for the relation $V_{\text{water}}([\text{IDRO1}])$
$h_{\text{water1}}$	17	m	Height limit of the river for parameters a1,b1,c1
$a1$	46	-	Coefficient for Q(h) when $[\text{IDRO1}] < h_{\text{water1}}$
$b1$	-902	-	Coefficient for Q(h) when $[\text{IDRO1}] < h_{\text{water1}}$
$c1$	4658	-	Coefficient for Q(h) when $[\text{IDRO1}] < h_{\text{water1}}$
$h_{\text{water2}}$	22	m	Height limit of the river for parameters a2,b2,c2
$a2$	60	-	Coefficient for Q(h) when $[\text{IDRO1}] < h_{\text{water2}}$
$b2$	-1350	-	Coefficient for Q(h) when $[\text{IDRO1}] < h_{\text{water2}}$
$c2$	8000	-	Coefficient for Q(h) when $[\text{IDRO1}] < h_{\text{water2}}$
$h_{\text{max}}$	25.3	m	Max height level of river and limit for use parameter a3,b3,c3
$a3$	96		Coefficient for Q(h) when $h_{\text{water2}} < [\text{IDRO1}] < h_{\text{max}}$
$b3$	-2800		Coefficient for Q(h) when $h_{\text{water2}} < [\text{IDRO1}] < h_{\text{max}}$
$c3$	22500		Coefficient for Q(h) when $h_{\text{water2}} < [\text{IDRO1}] < h_{\text{max}}$

WEIGHT OF THE STACK			
<b>Ps</b>	10710	kN	Plank weight on the stack
<b>Ppu</b>	1680	kN	Weight of single pulvino
<b>Ptp</b>	1601	kN	Weight of the trunk of pylon
<b>Pb</b>	1007	kN	Weight of the single beam
<b>Pp</b>	44	kN/m	Weight per meter of pylon
<b>Mt</b>	9720	kNm	Moment generated asymmetry
SHIFTING WEIGHTS			
<b>N(A1)</b>		kN	Axial load for load combination A1
<b>Mxx(A1)</b>		kNm	Bending moment for load combination A1
<b>Myy(A1)</b>		kNm	Bending moment for load combination A1
<b>N(A2)</b>		kN	Axial load for load combination A2
<b>Mxx(A2)</b>		kNm	Bending moment for load combination A2
<b>Myy(A2)</b>		kNm	Bending moment for load combination A2
<b>N(A3)</b>		kN	Axial load for load combination A3
<b>Mxx(A3)</b>		kNm	Bending moment for load combination A3
<b>Myy(A3)</b>		kNm	Bending moment for load combination A3
Vehicle braking			
<b>F<sub>r</sub></b>	206	kN	Value of the force due to the braking
<b>n</b>	3.3	m	“arm” for the vehicle braking moment