A glass and stainless steel truss

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SUMMARY. Glass has all mechanical characteristics required for structural use, but it has a bad one that limits its use: it is brittle. In the last years, the great development of glass knowledge and technology give an incentive to study and improve the structural use of glass, in particular of laminated glass. The main concept is to couple laminated glass with steel to exploit their characteristics of great compression strength and great tensile strength respectively. The structure presented in this paper has the classical features of a typical plane truss and the design provides that each element, both compressed and tight, is composed by double-elements to get a better performance towards lateral stability and to guarantee the symmetry of the truss. In this paper both static and dynamic analyses are performed. In addition, some experimental tests are conduced to feel the behavior of glass components of the truss.

1 INTRODUCTION

Glass is an ancient material, known by people since the Stone Age, so why is it not used more often as a structural material? Architects loved glass because it has a great transparency and it does not obstruct view or visually interrupt an open space. Structural engineers should love it because theoretically it could be mechanically compared to usual structural materials like steel and concrete. But in practice, glass is used only in few applications. Both social and physical motivations limit a large acceptance of glass a structural material. The social limitations include the psychological effects of having no privacy and the perception of its brittleness, its physical limitation [1].

Glass has all mechanical characteristics required for structural use (Young's modulus of about $70000 N/mm^2$, compression strength of about $200 N/mm^2$, tensile strength of about $100 N/mm^2$) [2], but it has a bad mechanical characteristic that limits its use: it is brittle. Brittle nature of glass is confirmed by the fact that it fails in tension and not in shear, it deforms very little before breaking, and it develops forked fractures due to internal stresses. Glass is a homogeneous and isotropic material, but it is also amorphous. Because of this absence of a defined microscopic structure, glass structural use is influenced by the presence of microscopical flaws. These flaws, congenital or gained, cause concentrations of stress. Glass cannot redistribute internal forces and because of that intense stress concentrations it breaks [3].

In the last years, the great development of knowledge and technology connected to glass gives an incentive to study and improve the structural use of glass. The term "structural glass" was born to describe a curtain wall when it was composed by glass panels [4]. In this constructive system the main structure is invisible because glass panels are glued each other with structural sealants. Today the tendency of use glass in real structural elements is growing, moving toward the limit of the glass.

So now is not infrequent to see major building components, like canopies, floors, stairs, beams and columns, made using glass. In this paper a glass truss is proposed.

1.1 *Glass structural elements*

During the nineteenth century, glazed roofs and canopies began to appear in buildings. Their popularity grew because they would allow natural light in the most internal areas of the building and they would give a feature of elegance and lightness to the space. In detail, these structures are composed with glass plates and a main structure, usually a steel structure, sustaining the glass. Another way to design the roof main structure is to use glass elements instead of steel elements. This practice is similar to the one used in glass façades, when they are sustained by vertical glass fins. In both cases, vertical fins and horizontal beams, the use of glass and the contemporary reduction of steel removes any visual obstructions from interior to exterior and vice versa. Examples of glass beams used in architecture are shown in Figs. 1 [5] and 2 [6].

Figure 1: Example of glass beams used to sustain a footbridge.

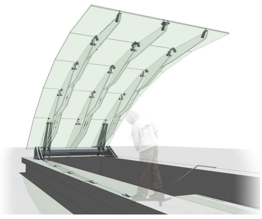


Figure 2: Glass canopy in Tokyo.

In these cases, the glass panes laminated together with PVB (polivinilbutirrale, a polymer) are put vertically and loaded in direction parallel to the medium plane. So these elements work as beams. The external restrains are usually realized with steel supports connected up with soft, elastic materials like nylon, neoprene, polyoxymethylate. In these beams the inner pane can support the entire load without the help of the outer panes, for safety reasons. Instead of classical beams, it is possible to design glass trusses. In this typology, glass elements are used and designed with steel elements. Examples of glass trusses are shown in Figs. 3 [4] and 4 [5].

In all these project, the main concept is to couple glass with steel to exploit their characteristics of great compression strength and great tensile strength respectively. The first example is called TVT, designed by the Department of Structural Engineering of University of Pisa and the second one is the roof structure of the restaurant of the Zwitserleven building in Amstelveen (The Netherlands)

Figure 3: TVT of University of Pisa.

Figure 4: Glass truss of the restaurant of the Zwitserleven building in Amstelveen.

[5]. The structure presented in this paper moves in the same direction of the truss shown in Fig. 4. Here the architect adopts this solution to give a particular feature of brightness to the restaurant below. The most relevant limits of this project are that glass is not used for the upper compressed current and the design of the entire structure is carried on because the span is rather small and so the dimensions of the elements are modest.

2 PRELIMINARY DESIGN

Unlike the last example of glass truss, the structure presented here is not for a specific case of study, but it can be used in many different situations.

The static configuration of the truss has the classical features of a typical plane truss, in fact it is composed by several triangles. Each element, both compressed and tight, is composed by double-elements to get a better performance towards lateral stability and to guarantee the symmetry of the truss. This first design provides that the cross section of laminated glass elements is rectangular, i.e. an economic solution, well suited for the industrial production. The use of laminated glass reduces the influence of buckling, but use of this type of glass under compression is delicate, because non-linear behavior of laminated glass is not completely well known [7].

There is a specifical design for the internal tight element: it is composed by a stainless steel cable covered by the same glass element that composes the compressed elements. This choice is taken for aesthetic reasons, because this element is, at the first sight, identical to the other ones. The external tight parts are made by stainless steel cables with a tendon to obtain the necessary tension in the element.

To ensure that the project is really feasible, a preliminary static design is performed. As explained above, glass is used in compressed elements. Although glass has very good compression strength, the brittle fail caused by possible bending stresses is the main problem with the structural reliability of compressed elements. The design criteria useful with brittle materials and elements is the one called "fail safe". This method is based on accepting that some elements can fail, without their break causes the collapse of the entire structure. The two key concepts of this approach are hierarchy and redundancy. The first consists to establish a specific function for each element in a hierarchic order; the second consists to ensure a fixed safety level when one or more elements are broken [4]. This approach is also suggested by the draft of prEN 13474-3 [8], that is the European standard for structural glass.

The influence area considered has dimensions of 6,90x1,50 m, where 6,90 m is the comprehensive length of the truss and 1,50 m is the distance between each truss. The materials used have the following characteristics (E is Young's modulus, ν is Poisson ratio, f_{gdc} is allowable maximum stress in compression for prestressed glass and f_{yd} is allowable maximum stress for steel):

$E_g = 73000 N/mm^2$; $\nu_g = 0.22$; $f_{gdc} = 200 N/mm^2$;

$E_s = 200000 N/mm^2$; $\nu_s = 0.3$; $f_{yd} = 220 N/mm^2$.

To transfer in the right way forces and stresses from glass to steel joints and vice versa, it is necessary to design the connection between the two materials. For these connections, use of nylon is designed, i.e. a synthetic polymer, known generically as polyamides. This material has $E = 3000 N/mm^2$ and has the necessary capability of distributing forces to and from the glass. So each end of the glass elements is covered by a nylon cap.

3 PROJECT OF THE GLASS TRUSS

The configuration of the truss examined in this paper is shown in Fig. 5. In this paper both static and dynamic analyses are performed. In addition, some experimental tests are conduced to feel the behavior of glass components of the truss.

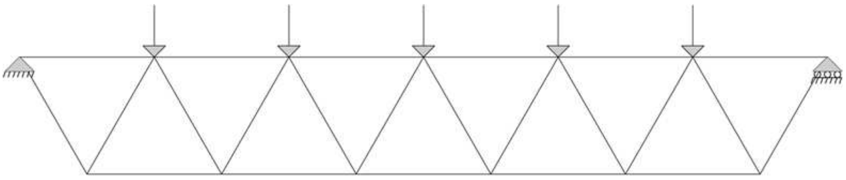


Figure 5: Static configuration of the truss.

3.1 *Static analysis*

The analysis uses three load cases involved in the possible use of the truss, i.e. self-weight, snow and wind, combined at the ultimate limit state with load partial factors prescribed by prEN 13474-3. In Tab. 1 are shown factors and values used to obtain loads to apply to the structure. G_{k1} is self-weight load, Q_{k1} is wind load and Q_{k2} is snow load while γ_G and γ_Q are loads partial factors.

For glass elements, as prescribed by European standard, compression and buckling load verifications are performed. Both verifications are satisfied and the obtained results are shown in Tab. 2. For determination of allowable stress of prestressed glass, it is used formula proposed in prEN 13474-3, where are involved values like $f_{g;k}$ (characteristic value for annealed glass, i.e. $45 N/mm^2$), $f_{b;k}$ (characteristic value for prestressed glass, i.e. $120 N/mm^2$) and some factors due to load duration, glass surface profile, strengthening of prestressed glass and material.

For stainless steel elements, tensile verification is performed as prescribed by EC3. The check is satisfied as shown in Tab.3.

$G_{k1} =$	300	daN/m^2
$Q_{k1}(wind) =$	130	daN/m^2
$Q_{k2}(snow) =$	150	daN/m^2
γ_G	$1,4$	
γ_Q	$1,5$	

Table 1: Load cases.

$N_{Ed}(snow) =$	60750	N
$f_{E;gd}(snow) =$	$7,06$	N/mm^2
$N_{Rd}(buck.) =$	1394655	N
$f_{R;gd}(compr.) =$	$73,25$	N/mm^2

Table 2: Verifications for glass elements.

$\phi 20mm$		
$N_{Ed}(snow) =$	64200	N
$N_{Rd}(snow) =$	68295	N
$\phi 8mm$		
$N_{Ed}(snow) =$	21950	N
$N_{Rd}(snow) =$	43709	N

Table 3: Verifications for steel elements.

Last but not the least, take a look at working stress values of all elements. It is easy to notice that the project realizes a strength hierarchy. As well known, strength hierarchy is the criteria which ensures that the structure will have a ductile break and not a fragile break, because the last type of break do not allow people to escape from the structure. So glass provides a fragile break and it is necessary to avoid the situation where glass breaks before steel. With performed calculations, steel ($\phi 20mm$ element) is almost carried till its own allowable stress, while glass is kept far from it and its working stress is rather small. In this way, ductile break happens before fragile break and everyone near the truss can notice that.

3.2 *Dynamic analysis*

In addition to static loads, the truss has to sustain dynamic loads in its working life, in particular wind and earthquake. To design the right behavior of the truss under these dynamic load cases, it is necessary to perform a modal analysis of the truss. Finding natural frequencies of the truss, it is possible to keep them far from the characteristic frequencies of wind and earthquake. Period and frequencies obtained by modal analysis for the first fifteen modes are shown in Tab. 4. In case of wind, truss own frequencies are higher of about two orders of magnitude than wind ones. In case of earthquake, small period ensures that low accelerations will affect the truss.

$Mode$	$T(s)$	$\omega(Hz)$
1	$0,048212$	$130,32$
2	$0,016302$	$385,43$
3	$0,014153$	$443,95$
4	$0,010449$	$601,33$
5	$0,007815$	$803,97$
6	$0,007352$	$854,64$
7	$0,006230$	$1008,49$
8	$0,005489$	$1144,77$
9	$0,004232$	$1484,67$
10	$0,003862$	$1626,75$
11	$0,003309$	$1898,77$
12	$0,003072$	$2045,59$
13	$0,002942$	$2135,71$
14	$0,002753$	$2282,18$
15	$0,002268$	$2770,11$

Table 4: Period and frequencies of the truss.

Checking of internal resonance is also conduced. In fact, two typologies of resonances are virtually dangerous for the truss: local resonance and global resonance.

The first type implies that natural frequencies of the truss could be similar to natural frequencies of one particular “local” element of the truss calculated by classical formulas for beam natural frequencies. This fact could be the case of failure of the same element if interests first modes. Fig. 6 shows design calculations of ratio between global frequencies of the truss and local frequencies of steel cables and glass beams: in this way, truss avoids the possibility of local resonance in first modes. The second type implies that one mode frequency could be multiple of another one. Also this fact could be dangerous if interests first modes; Fig. 7 shows that this possibility appears only in high modes, so it is not an issue.

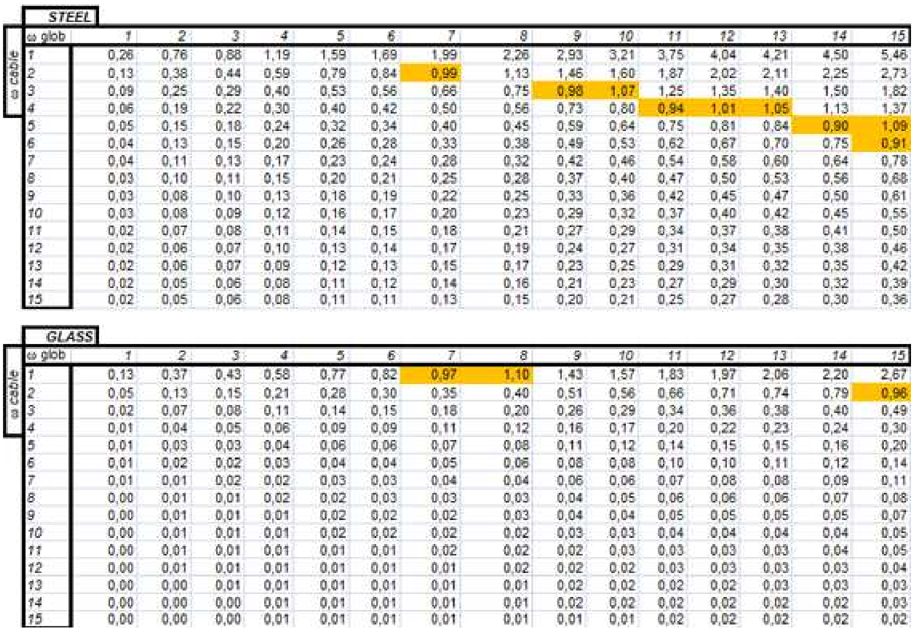
To complete dynamic analysis, it is conduced a parametric analysis, with use of steel cable length as variable parameter. Three different configurations are used in addiction to the first one and they are shown in Fig. 8. Length of cable in configuration of Fig. 5 are assumed as 1,00 value, so the other three configuration have cable lengths of 0,90, 0,75 and 0,60 respectively.

From a qualitative point of view, frequency has direct proportionality with stiffness. So it is expected that frequency decreases with the increase of the chosen parameter, because curve configurations are stiffer than straight one. But this fact happens only in the first two modes. Instead, as shown in Fig. 9, modes larger than the third present particular behavior: frequency decreases from 0,60 configuration to 0,90 configuration and then increases again at the 1,00 configuration.

3.3 *Experimental measurements*

To allow the design of a future prototype of the truss, a first set of experimental measurements is carried on. In particular both compression measurements and vibration measurements are performed.

Preliminary compression measurements are planned to measure the maximum load supported by the glass elements. Using Eulero formula for buckling load, the maximum load is expected from $98kN$ to $390kN$ (depending on boundary conditions). On the contrary, glass elements broke at about



STEEL

ω cable

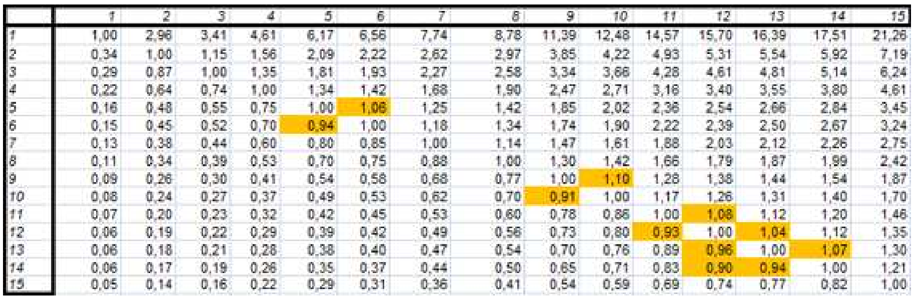
ω glob	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0,26	0,76	0,88	1,19	1,59	1,69	1,99	2,26	2,93	3,21	3,75	4,04	4,21	4,50	5,46
2	0,13	0,38	0,44	0,59	0,79	0,84	0,99	1,13	1,46	1,60	1,87	2,02	2,11	2,25	2,73
3	0,09	0,25	0,29	0,40	0,53	0,56	0,66	0,75	0,98	1,07	1,25	1,35	1,40	1,50	1,82
4	0,06	0,19	0,22	0,30	0,40	0,42	0,50	0,56	0,73	0,80	0,94	1,01	1,05	1,13	1,37
5	0,05	0,15	0,18	0,24	0,32	0,34	0,40	0,45	0,59	0,64	0,75	0,81	0,84	0,90	1,09
6	0,04	0,13	0,15	0,20	0,26	0,28	0,33	0,38	0,49	0,53	0,62	0,67	0,70	0,75	0,91
7	0,04	0,11	0,13	0,17	0,23	0,24	0,28	0,32	0,42	0,46	0,54	0,58	0,60	0,64	0,78
8	0,03	0,10	0,11	0,15	0,20	0,21	0,25	0,28	0,37	0,40	0,47	0,50	0,53	0,56	0,68
9	0,03	0,08	0,10	0,13	0,18	0,19	0,22	0,25	0,33	0,36	0,42	0,45	0,47	0,50	0,61
10	0,03	0,08	0,09	0,12	0,16	0,17	0,20	0,23	0,29	0,32	0,37	0,40	0,42	0,45	0,55
11	0,02	0,07	0,08	0,11	0,14	0,15	0,18	0,21	0,27	0,29	0,34	0,37	0,38	0,41	0,50
12	0,02	0,06	0,07	0,10	0,13	0,14	0,17	0,19	0,24	0,27	0,31	0,34	0,35	0,38	0,46
13	0,02	0,06	0,07	0,09	0,12	0,13	0,15	0,17	0,23	0,25	0,29	0,31	0,32	0,35	0,42
14	0,02	0,05	0,06	0,08	0,11	0,12	0,14	0,16	0,21	0,23	0,27	0,29	0,30	0,32	0,39
15	0,02	0,05	0,06	0,08	0,11	0,11	0,13	0,15	0,20	0,21	0,25	0,27	0,28	0,30	0,36

GLASS

ω cable

ω glob	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0,13	0,37	0,43	0,58	0,77	0,82	0,97	1,10	1,43	1,57	1,83	1,97	2,06	2,20	2,67
2	0,05	0,13	0,15	0,21	0,28	0,30	0,35	0,40	0,51	0,56	0,66	0,71	0,74	0,79	0,96
3	0,02	0,07	0,08	0,11	0,14	0,15	0,18	0,20	0,26	0,29	0,34	0,36	0,38	0,40	0,49
4	0,01	0,04	0,05	0,06	0,09	0,09	0,11	0,12	0,16	0,17	0,20	0,22	0,23	0,24	0,30
5	0,01	0,03	0,03	0,04	0,06	0,06	0,07	0,08	0,11	0,12	0,14	0,15	0,15	0,16	0,20
6	0,01	0,02	0,02	0,03	0,04	0,04	0,05	0,06	0,08	0,08	0,10	0,10	0,11	0,12	0,14
7	0,01	0,01	0,02	0,02	0,03	0,03	0,04	0,04	0,06	0,06	0,07	0,08	0,08	0,09	0,11
8	0,00	0,01	0,01	0,02	0,02	0,03	0,03	0,03	0,04	0,05	0,06	0,06	0,06	0,07	0,08
9	0,00	0,01	0,01	0,01	0,02	0,02	0,02	0,03	0,04	0,04	0,05	0,05	0,05	0,05	0,07
10	0,00	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,04	0,04	0,04	0,04	0,05
11	0,00	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,04	0,05
12	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,04
13	0,00	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03
14	0,00	0,00	0,00	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,02	0,02	0,03
15	0,00	0,00	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,02

Figure 6: Ratios for local resonance.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1,00	2,96	3,41	4,61	6,17	6,56	7,74	8,78	11,39	12,48	14,57	15,70	16,39	17,51	21,26
2	0,34	1,00	1,15	1,56	2,09	2,22	2,62	2,97	3,85	4,22	4,93	5,31	5,54	5,92	7,19
3	0,29	0,87	1,00	1,35	1,81	1,93	2,27	2,58	3,34	3,66	4,28	4,61	4,81	5,14	6,24
4	0,22	0,64	0,74	1,00	1,34	1,42	1,68	1,90	2,47	2,71	3,16	3,40	3,55	3,80	4,61
5	0,16	0,48	0,55	0,75	1,00	1,06	1,25	1,42	1,85	2,02	2,36	2,54	2,66	2,84	3,45
6	0,15	0,45	0,52	0,70	0,94	1,00	1,18	1,34	1,74	1,90	2,22	2,39	2,50	2,67	3,24
7	0,13	0,38	0,44	0,60	0,80	0,85	1,00	1,14	1,47	1,61	1,88	2,03	2,12	2,26	2,75
8	0,11	0,34	0,39	0,53	0,70	0,75	0,88	1,00	1,30	1,42	1,66	1,79	1,87	1,99	2,42
9	0,09	0,26	0,30	0,41	0,54	0,58	0,68	0,77	1,00	1,10	1,28	1,38	1,44	1,54	1,87
10	0,08	0,24	0,27	0,37	0,49	0,53	0,62	0,70	0,91	1,00	1,17	1,26	1,31	1,40	1,70
11	0,07	0,20	0,23	0,32	0,42	0,45	0,53	0,60	0,78	0,86	1,00	1,08	1,12	1,20	1,46
12	0,06	0,19	0,22	0,29	0,39	0,42	0,49	0,56	0,73	0,80	0,93	1,00	1,04	1,12	1,35
13	0,06	0,18	0,21	0,28	0,38	0,40	0,47	0,54	0,70	0,76	0,89	0,96	1,00	1,07	1,30
14	0,06	0,17	0,19	0,26	0,35	0,37	0,44	0,50	0,65	0,71	0,83	0,90	0,94	1,00	1,21
15	0,05	0,14	0,16	0,22	0,29	0,31	0,36	0,41	0,54	0,59	0,69	0,74	0,77	0,82	1,00

Figure 7: Ratios for global resonance.

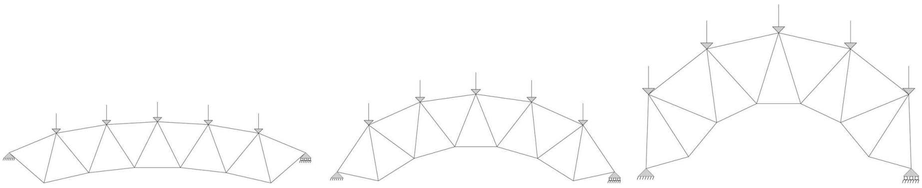


Figure 8: Other configurations of the truss.

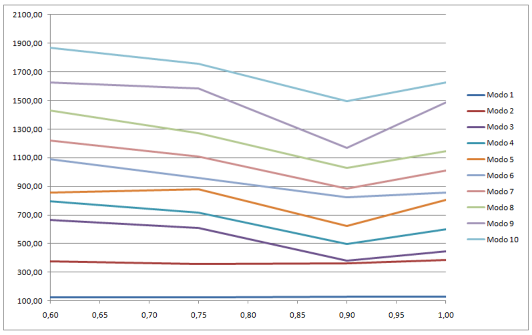


Figure 9: Length-frequency trend.

only $58kN$, with a particular breakage way: it is not present PVB separation, but longitudinal cracks appear within glass panels (see Fig. 10). Probably, aleatory nature of elastic modules is the reason of difference between theoretical predictions and measurements. This fact needs more studies, in particular to determinate the specifical role of elastic modules, for example using micromechanical model, developed both for the analysis of long-fiber composites and for masonry [9].

Figure 10: Glass element at the end of compression measurement.

Vibration measurements are conduced to find the characteristic modal parameters of the glass elements, i.e. natural frequencies, modal shapes and modal damping. Using a Brüel&Kjær equipment [10], three different boundary conditions are considered: free-free, clamped-clamped and hinged-hinged. Fig. 11 shows the experimental configuration for free-free beam, with accelerometers and hammer. It is also important to focus to temperature conditions, because natural frequencies and damping are affected by temperature in significant way. In fact, some results can be not compared if temperature conditions change between measurements (although slightly).

To compare the experimental data with preliminary theoretical predictions, the first three natural frequencies have been computed considering monolithic beam without PVB lamination. It is expected that the experimental frequencies will be lower than calculated ones, both because PVB introduces damping in glass beams and because beam is stiffer without PVB, so frequencies have to decrease in any way. Then, to have a more accurate comparison, FE analyses have been performed. In particular looking to modal shapes, to check that first modes do not interest some motions of PVB interlayer. FEM is three-dimensional model, as shown in Fig. 13, and it is important to notice that out-of-plane modal shapes appear in modes larger then fifth (depending on boundary conditions).

Figure 11: Configuration of vibration measurement.

		free-free		clamped-clamped		hinged-hinged	
$Mode$		$\omega(Hz)$	ξ	$\omega(Hz)$	ξ	$\omega(Hz)$	ξ
1	$experimental$	420	$0,042$	410	$0,056$	290	$0,088$
	$theoretical$	1.048		1.048		462	
	FEM	450		370		250	
2	$experimental$	700	$0,026$	945	$0,026$	730	$0,041$
	$theoretical$	2.887		2.887		1.848	
	FEM	550		972		664	
3	$experimental$	1.095	$0,042$	1.945	$0,027$	1.350	$0,037$
	$theoretical$	5.662		5.662		4.160	
	FEM	890		1.870		1.485	

Table 5: First three natural frequencies.

FFT analysis from accelerometer signals acquired by measurements in time domain has been performed. This first experimental set is devoted mainly to find natural frequencies and estimation of modal damping. To do this some graphical methods are employed. For example, application of them is shown in Fig. 12. As well known, FFT analysis transforms signals from time domain to frequency domain. To find first natural frequencies, i.e. ω_1, ω_2 and ω_3, peak picking method is used: each peak corresponds to one natural frequency of the system. Using instead half-power bandwidth, system damping, i.e. ξ_1, ξ_2 and ξ_3, can be estimated: width of FFT graph in correspondence to ω_n at a fixed value ($acc_{max}/\sqrt{2}$) provides an estimation of damping. Results obtained are shown in Tab. 5.

As one can see, ratios between ω *"theoretical"* and ω *"measurements"* of all boundary conditions are generally the same, i.e. frequencies decrease as expected. This fact is due to damping ξ, neglected in monolithic calculations. In addiction, ratios between ω *"FEM"* and ω *"measurements"* are closer to unity than the previous ones. In FE model PVB interlayer is considered and it is another fact that confirms that it plays an important role in laminated glass vibrations. Looking then at ξ values, it is easy to notice that they are rather not homogeneous and this fact is probably due to graphical method used to obtain them and to not very clean accelerometer signals.

4 CONCLUSIONS

In this paper a glass truss is presented. A static analysis is performed and both glass verifications and stainless steel verifications are satisfied. It is also important that the project realizes a strength hierarchy, with performed calculations, because steel ($\phi 20mm$ element) is almost carried till its

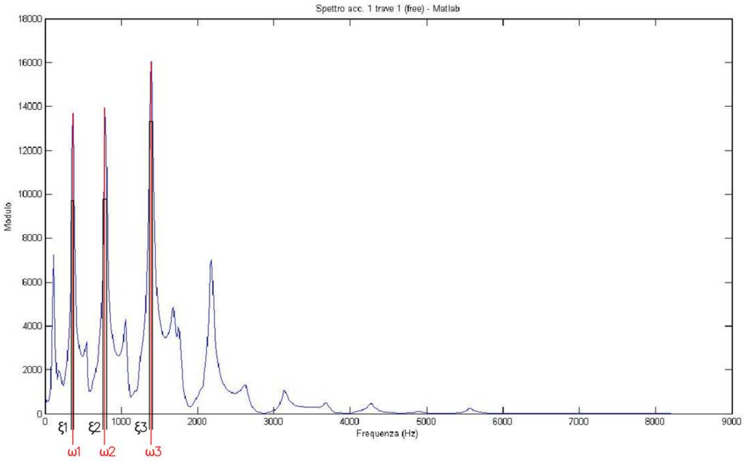


Figure 12: Peak-picking graphical method for ω and ξ.

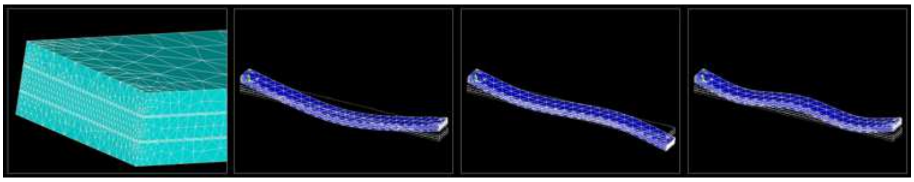


Figure 13: Mesh and first three modal shapes calculated by FE (free-free).

own allowable stress, while glass is kept far from it. In this way, ductile break happens before fragile break. Then dynamic analysis is performed. Finding and checking natural frequencies of the truss, it is possible to keep them far from the characteristic frequencies of wind and earthquake. In case of wind, truss own frequencies are higher of about two orders of magnitude than wind ones. In case of earthquake, small period ensures that low accelerations will affect the truss. Checking of internal resonance is also conduced, both local between truss and each element type and global between each mode. Results confirm that internal resonance appears only in high modes.

To allow the design of a future prototype of the truss, a first set of compression and vibration measurements is carried on. In compression measurements, glass elements broke at about $58kN$, with not PVB separation, but with longitudinal cracks within glass panels. Vibration measurements are used to conduce FFT analysis from accelerometer signals acquired by measurements in time domain. This first experimental set is conduced mainly to find natural frequencies and an estimation of modal damping; in future a second set will be performed to find all parameters. For now, some good results are obtained because they are generally in accord to FE analysis and to some manual calculations.

This paper is concerned with the initial part of this complex structure of a glass and stainless steel truss. Many things have to be done to complete the project. In particular, experimental tests regarding better maximum buckling load and behavior before break of glass element. Also it will be important to do other vibration measurements to find natural frequencies, modal shapes (not only lower, but also higher ones) and damping in a different way. Another aspect is the technological one: all joints and connections have to be designed in all their parts. By the way, works and studies shown in this paper demonstrate that “a good way” has been taken.

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