PROBLEMS CONCERNING ANALYTICAL AND EXPERIMENTAL STRUCTURAL ANALYSIS OF LIGHTWEIGHT STEEL STRUCTURES

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ABSTRACT
Since the 90’s one has observed a massive import of western European lightweight structures that have begun a second life in Romania. For mounting these “second hand” structures in Romanian locations, usually designers limited themselves ONLY to activities of redesigning of foundations in concordance with the foundation terrains. This way it is assumed that these structures correspond to the safety and comfort in usage requirements. In fact, expert surveys show the need for structural reinforcements, both for stability purposes and for correcting the dynamic response (usually expressed by displacements caused by the dynamic load of the wind). In the paper, the authors present the problems of expert survey and reinforcements of lightweight steel structures according to the stability and strength requirements to static and dynamic loads correlated to the cost requirements of the beneficiaries.

INTRODUCTION
Introduction in the construction practice of lightweight steel structures, having complex forms and compositions, has constituted and constitutes an important stage in the rational management of material and human resources, such that these lead to optimal economic output. In this context, starting with the 1990’s one can observe a massive import of “second hand” lightweight steel structures. It has to be taken into account that in the present, for the elaboration of construction authorizations, legislation is limited, in terms of strength and stability, only at the existence of the foundation plans. According to these terms many designers and verifiers usually limit their work to activities of redesigning the foundations according to the foundation terrains. In the majority of cases, structural surveys of these constructions reveal the necessity of structural reinforcements, both due to stability problems and for correcting the dynamic response. Numerous collapses of lightweight steel structures in the late years (2000-2010), should constitute a serious alarm signal.
MATERIALS AND METHODS

1. Expert study and verification aspects for lightweight steel structures

In the case of lightweight steel structures, problems that can cause major changes of structural safety can be grouped in the following classes:

- Problems connected with the quality of the base material (resistance to flow, different types of fragile rupture, lamellar distancing, etc.).
- Problems concerning local and general stability (thin wall fogging, core or base fogging, etc.).
- Fatigue and repeated loading problems.
- Buckling problems.
- Deformation problems caused by static and dynamic loads.
- Problems caused by corrosion and erosion.

Lightweight steel bearing structures are slim structures having complex forms and compositions and are characterized by stability phenomena strongly dependent on the fundamental geometry; namely, dependent on the initial equilibrium state (which encompasses both geometrical and physical imperfections), based on the structure’s own weight and the possible existing pre-tensioning.

A phenomenon particular to these structures is the loss of general stability caused by the propagation in the entire structure of a local instability mode. The loss of stability through “SNAP” has a strongly dynamic character is proportionally important to appearance large accelerations during the bounce; large accelerations implicitly cause very large inertial forces.

Thus in the case of flat structures \( f/l = 0.03 – 0.06 \) accelerations reach up to circa 10 – 12 \( m/s^2 \). It has to be mentioned that the loss of stability through “SNAP”, that is through dynamical bounce, can also appear in the case of lightweight structures that are not exactly flat. Thus, the old dome of ROMEXPO – Bucuresti, having an arch of 17.9 m and a diameter of 93.5 m \( f/l = 0.19 \) collapsed through “SNAP”, both due to the effect of superimposition of wind blasts over a local load caused by the agglomeration of snow and due to the insufficient rigidity of nodes having an elastic composition [1], [2], [3].

A decisive element of the expert surveys and verification activities is the process concerning the fulfillment of the drift conditions, remanent drift, limited rotation capacity of bars and joints and resistance to fatigue (oligocyclic).

Taking into account that the relative level drift, namely the rigidity criterion, governs the structure’s behavior, obeying the limit values is mandatory.
The resistance to oligo-cyclic fatigue will be studied based on the secondary tensions (caused by vibrations or by the daily thermal expansion-contraction) taking into account the intensity of the tension’s time interval.

2. Lightweight steel structure’s loads

The main loads of lightweight steel structures are given by the proper weight, wind pressure, temperature, dynamic loads (given by the equipment functioning inside the structure or by seism) and supports displacements which are analyzed independently depending on the type of the structure and on its importance.

2.1. Weight influence

During the design and verification phases of lightweight structures the specialist must take into account the following effects resulting from the weight combined with loads or actions from other causes:

a. Active actions. These actions are given by the weight of rainfall water (in the situation when the ceiling sink rain water tapes are blocked) and by the weight of snow or/and ice.

b. Inactive actions. These actions are composed by the weight of structural elements, insulations and permanent loads

2.2. Wind load

The maximum work pressure caused by the wind is ascertained as being the most severe combination of interior and exterior pressures.

When designing the structure one has to consider that any increase in pressure which can act upon the structural elements must be absorbed by the structure obeying the safety criteria.

2.3. Environmental temperature influence

It is mandatory to take into account the action caused by the environmental temperature. Structural elements having a minimum acceptable temperature below 0°C, will be additionally loaded with ice formed by the atmospheric humidity condensation.

For tubular structures, by the cooling of vapors or gases housed inside the tubes, their interior pressure can drop sufficiently such that an interior void appears. In this situation, tube-like structural elements must be able to take over the exterior pressure of low temperature

2.4. Dynamic effects influence

Lightweight steel structures are verified for the damaging effects of vibrations which can be caused by various sources like:

- impact forces,
- resonance produced by the functioning of compressors or other types of equipment composing the air-conditioning installations, fans, loud noises, traffic, etc.,
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2.5. **Thermal dilation and contraction effects influence**

During the verification of lightweight steel structures one must take into account the thermal contraction and dilation effects combined with loads produced by other causes.

* a. *Thermal loads caused by constraints (pitching)* which are composed of stresses that appear when the free dilation and contraction of structural elements is obstructed by different fixed supports or anchoring points.

* b. *Loads that appear at structure* which are built using construction materials having different thermal dilation coefficients (such as steel or aluminum).

3. **Aspects concerning the flexibility of lightweight steel structures**

A lightweight steel structure must have sufficient flexibility such that the temperature variations and the initial cession combined with other influences don’t determine:

- problems in the joints of structural elements,
- overstressing in the supports,
- compromise of the equipments and cover fixed to the structure.

The fulfillment of these requirements is realized through:

- determination of the maximum effective displacements and assuring their limitation in the admissible interval,
- determination of the effective interval of tensions produced by different causes and assuring their limitation,
- limitation of the connection forces from the supports in the connection points of the equipments and of the cover.

For large-span lightweight structures, due to the large interval of generation of the displacements variations and with the purpose of associated stresses reduction, in the support zones or in other points of the structure, initial displacements or assembly displacements are introduced. These are called compensation displacements (similar to the notion of counter-arch) [4], [5], [6].

It is mandatory to sum up these displacements to the displacements resulting from the other loads, thus obtaining the total maximum displacements, which have to remain below the admissible ones.

For lightweight steel structures exhibiting a linear elastic behavior, namely when the stresses remain proportional to the displacements, usually tensions concentrations do not appear. In the case of structures characterized by a non-linear behavior, the concentrations of uncontrolled tensions can have dangerous effects over the structural safety. Besides the fact that it
reduces the static indetermination degree, the appearance of plastic joints
determines plastic deformations which can be very large compared to the
elastic displacements.

4. Structural analysis problems
For identifying the materials from lightweight structures constructed
from steel it is necessary to perform a minimum number of in situ an-
laboratory experimental tests.
For the existing mounted structures, the in situ experimental analysis
phase allows obtaining the following information:
- Dynamic characteristics of the structure.
- The behavior of slender structures subject to the actions of seism
  and wind.
- Evaluation of the magnitude order of the deformations and
displacements resulted from symmetrical and non-symmetrical
loads, taking care that the intensity of the load does not surpass
under any circumstances the value of the real load taken into
account [7], [8], [9], [10].
The following tests are performed in the laboratory:
  • Axial stretching test
    This test serves determining the following:
    - apparent flow limit,
    - rupture (breakage) limit,
    - creeping at rupture.
  • Hardness test (Brinell)
    For this test minimum three traces are used. For each trace two
diameters are measured, such that the difference between them is less or
equal to 2%.
  • Resilience test (Bending through shock test)
    Usually, for this test, eight U-type test specimens and 8 V-type test
specimens are necessary. Depending on the loading conditions, materials
can exhibit either a tough or fragile behavior.

5. Stability of the lifetime of the structure
The lifetime of the structure expresses the built-in reliability in years,
namely the probability that the structure fulfills the prescribed mission, at
least for a certain time interval, in the specified utilization conditions [11],
[12], [13], [14].
The procedure is based on the determination of the loading history,
using a method of numbering and classification, respectively on the stress
gauges histograms delta_sigma_i (measured and computed).
By accepting the principle of linear accumulation (Palmgren, Langer and Miner) the annual harm is computed ($S_{\text{year}}$).

The probable lifetime interval is computed using $L_f = 1 / S_{\text{year}}$

6. **Lightweight steel structures constructed using SANDWICH type materials**

   Lightweight steel structures using SANDWICH type materials are part of the category of highly efficient lightweight structures due to a set of attributes which is not exhibited by any other type of materials, like:
   - the variety of building forms,
   - durability,
   - propitious behavior to seism,
   - remarkable thermal insulation,
   - the possibility to be built on any type of foundation terrain with minimum costs during any season of the year.

   In the domain of construction structures, SANDWICH type materials, namely stratified materials, in cooperation or composite, which couple the properties of each composing layer, are used in practice since the 1960’s.

   There exist many sorts of SANDWICH type materials, owing to the diversity of materials that are forced to cooperate.

   Nowadays, the most frequently used materials are composed of two exterior metallic layers and a connection layer made of plastic material, which structurally connects the metallic layers.

   The finned or flat metallic layers, which compose the visible exterior sides of the composite material, are made of steel or aluminum having a thickness of circa 0.5 – 1.5 mm. The intermediate connection layer is made of reduced density polymers ($10 – 50 \text{ kg/m}^3$), like:
   - polyurethanes foam,
   - polystyrene having a thickness or circa 40 – 100 mm.

   The exterior layers are designed to work tension and compression, while the intermediate layer, which connects the exterior layers, must be able to take over the sliding forces.

   The expert studies and verification of these structures must focus on the local and general co-operation phenomena, such that the structural safety enforced by legal norms is attained. Experimental test are necessary for many reused (second hand) important structures, taking into account that they are composed of different SANDWICH type materials. These tests are performed both for individual materials composing the layers and for the composite structure as an assembly.

   Tests performed on the materials that are part of the composite are usual, current tests.
Tests performed on the composite structure as an assembly focus on surprising the inner connection between the layers. The minimal tests are:
- tension test,
- bending test (for console-type static schemes, total and partial support on 2 or 4 edges, etc.),
- shearing test,
- torsion test.

When performing the static analysis of SANDWICH type structures having exterior walls without fins, one can neglect the proper bending rigidity, thus the inertial moment of the assembly having the following form:

\[ I_{\text{SANDWICH}} = 2Bt\left( H - \frac{t}{2} \right)^2 \]

where:
- B – width of the pane,
- t – the thickness of the exterior layer,
- H – height of the pane.

When computing the deformations it has to be taken into account the deformation caused by the shearing force of the core, considering that the deflections from the bending moment and from the shearing force have the same order of magnitude.

Based on these aspects, structural analysis using the Finite Element Method must be performed with discernment; otherwise the results will be distorted.

7. Structural intervention aspects

Structural interventions have as final purpose the introduction of rational and economic changes in the existing structure, taking into account the structures purpose and the attributes of the existing composing structural materials [15], [16].

The current knowledge involving realizing structural interventions involve in the first place complete data about the physical and mechanical properties of the structural materials, both for the basic structure and the possible materials used during the intervention. In the second place it assumes the selection of a certain intervention procedure depending on the type of the basic structure together with the value on the exterior loads.

Structural interventions at lightweight steel structures take the form of repairing operations, consolidation operations, remodeling and rehabilitation [17], [18].
When the structural intervention is designed it is recommended to pass through three distinct phases:
- Study phase (range 1:100).
- Technical design phase (range 1:100).
- Execution design phase (range (1:50…1:1).

It is already known that in order for the modified bearing structures to be able to take over increased loads after structural interventions, these have to be correctly composed. This aspect presumes a correct fixation of the assembly of interconnected composing elements (initial, modified and added structural elements) with respect to the foundation medium or another stable construction, such that all of them form a geometrically fixed system, non-displaceable, geometrically invariable according to Euclid’s model.

The avoidance of the mechanism character (cinematic chain or cinematic system) of the structure, after the interventions, is obtained through the correct disposal of the necessary number of connections. This number has to be equal or greater than the number of degrees of freedom of the assembly of composing elements, both between the elements (interior connections) and for the ones between the structure and the fixation base (exterior connections – supports).

CONCLUSIONS
The expert study of reused lightweight steel structures represents a very complex problem. The inspection of the bearing capacity will be conducted in three phases (the pass from an inferior inspection stage to a superior inspection stage will be done only in the case when the results obtained in the analyzed phase are not concluding), in the following manner:

Phase 1:
- Identification of the construction materials through physical, mechanical and chemical analyses.
- Simplified static analysis, including the inspection to fatigue in the connection zones.

Phase 2:
- Static and dynamic analysis (including static and dynamic stability) taking into account the spatial compound effect of the structure.
- Lifetime computation for the structure considering future loads during its service periods.

Phase 3:
- In situ tests (in static regime and is recommended in dynamic regime too) including the exact determination of the
structure’s geometry grounded on topographic bases. Also, during this phase the possible existing counter-arches are measured including the straightness of structural elements (beams and poles). In the case of very high lightweight structures (e.g. mobile telephony antennas) dynamic topography will be used by recording the oscillatory movements or the vibrations of the construction caused by dynamic loads.

REFERENCES
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