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ENGINEERING ALGORITHM FOR WOOD FRAMES WITH CONTINUITY IN NODES AND HYBRID AREAS FRAMES DESIGNATED FOR RESIDENTIAL BUILDINGS

BY

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Abstract. The design of wood frames with continuity in nodes and hybrid portions (timber composite strips) is complex as a result of the use of two materials, of the structural composition and of the iterations which are necessary for the defining the solutions.

Partial hybridisation (hybrid areas) of the wood beams is made with thin strips (max 4 mm thickness) due to economic conditions. The composite strips are made of identical lamellas like unidirectional matrix – type lamella.

In the unidirectional fabric, for obtaining a maximum effect, the fabric threads are parallel to the wood fibres from the hybrid beam.

The paper presents the engineering algorithm of these structures and comprises the following stages: fixed form, pre-dimensioning of the composite strips, the equivalent form, iterations of the equivalent form.

Key words: hybridization; flexibility; wood frames; wood – strips; composites.

1. Introduction

The functional flexibility is the requirement which leads, most of the times, to the embracement, by the design engineers, of the structures made of frames.

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The optimum materials for frame structures are the ones which have strengths and elasticity moduli with high values, which have the ratio between compressive strength and the elongation approximately 1, and in the same time, which have the availability when made which would provide nodes continuity.

Obviously, based on these considerations, steel represents the ideal material for the development of the frame structures.

The increased price of the steel and the expensive measures for fire protection and anticorrosive measures are elements which temper (limit) the use of steel on a large scale for this type of structure.

A special case is represented by the reinforced concrete, which is practically a type II composite (the matrix, the concrete being a type I composite –and the reinforced stage comprises of steel bars), which provides, from the point of view of nodes continuity, the most rapid and less expensive composition.

Considering the strengths values and the compressive – tensile strengths ratio, timber can be a more suitable choice; but it presents the disadvantages provided by the decreased value of the longitudinal elasticity module 10.000 MPa, and by the fact that they are not studied, on a large scale, compositions of structures with nodes continuity.

In order to diminish these disadvantages, in the Secu & Roşu (2013) and Secu (1997) references the following solutions are presented:

a) assembling the timber frame structures for obtaining nodes continuity;

b) hybridisation (obtaining transversal sections of wood and composite strips) of some areas of the elements of the spatial framework.

The aim of this work consists of the design algorithm for timber frames upgraded with the solutions of the Secu & Roşu (2013) and Secu (1997) works.

2. Obtaining a Fixed Form

The fixed form, marked "ff", is the timber spatial frame which, in order to upgrade from rigidity conditions or from carrying capacity of the constructive beams, hybrid areas are created (composite wood – strips).

Obtaining "ff" is based considering the following:

a) the architectural conditions of the residential building;

b) the maximum dimensions, functionally accepted, for the framing elements (main collumns and beams);

c) pre-dimensioning of the perimetral closing elements, of the roof, floor structure and interior delimitation from the point of view of the performance levels requested by the imposed criteria (hydro-thermal and acoustic);

d) the market offer regarding the dimensions of the wood bench;

e) the market offer regarding the metallic elements (plates, corners, rods) for the joint of the wood benches.

Starting from these elements the following stages are followed:

a) pre-dimensioning of secondary beams;

b) pre-dimensioning of frame elements (main collumns and beams) ;

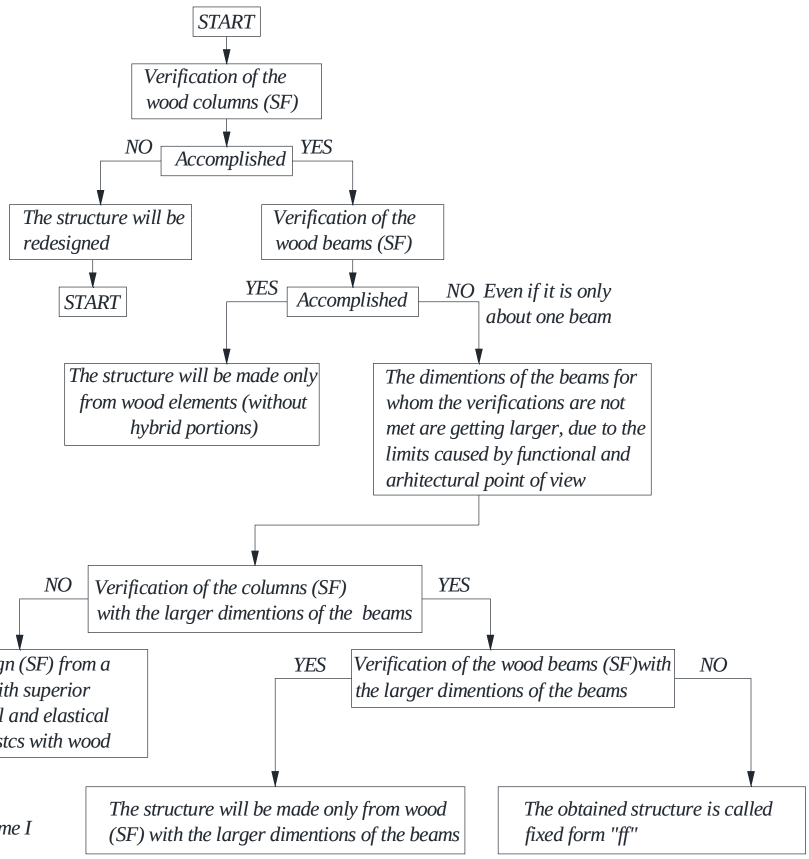
c) correlation of the frame elements related to the market offer and the specific composition;

d) computation of secondary beams (verifications of the carrying capacity and stiffness);

e) assessment of loads necessary for the strength and stiffness checking;

f) verifications of carrying capacity and stiffness of the frame elements (main beams, columns and nodes) with the values of the obtained efforts and displacements obtained from the structure computation.

As a result of elements verifications of the spatial timber frame (SF) decisions are to be made according to the logical Scheme I.



Logical scheme I

3. Pre-Dimensioning of Composite Lamella.

The “ff” upgrades refer to the hybridisation of the transversal sections on some areas of the beams. These areas belong to the beams on which the verifications of the carrying capacity or stiffness are not observed.

In this paper, the hybrid elements were composed by strips and timber.

The composite stratifications with maximum efficiency, in case of the beams of spatial timber frames, are made of identical lamellae with identical orientations.

The lamellae are matrix-type lamellae – longitudinal reinforcement and the reinforcement for maximum efficiency is disposed in parallel to fibres of wood on which the strip is located.

In practice, the unidirectional fabric is used as reinforcement (the warp is the longitudinal reinforcement and the weft is scarce and only has the role of maintaining parallel the threads of warp).

In this case, identical lamellae with identical orientations, the product and the lamella are having the same elastic and mechanic characteristics (in practice only one lamella cannot be used because of its reduced thickness of approximately 0.1 mm).

There are two situations that can be considered:

a) composite lamella is selected, as a prefabricated material, from the offer of a specialised manufacturer;

b) lamella is created (conceived) by the design engineer.

In case of conceiving, the necessary steps for the pre-dimensioning of the composite lamella are indicated in the logical Scheme II.

The annotations from the logical Scheme II have the following specifications: E_{wood} is the longitudinal elasticity module of wood; E_f – longitudinal elasticity module of warp threads; $R_{i,i,1}$ – tensile resistance, from bending, along the timber fibres, having the computed value; X_f – tensile resistance of the warp threads with the computed value; V_f – the volumetric fraction of the warp threads.

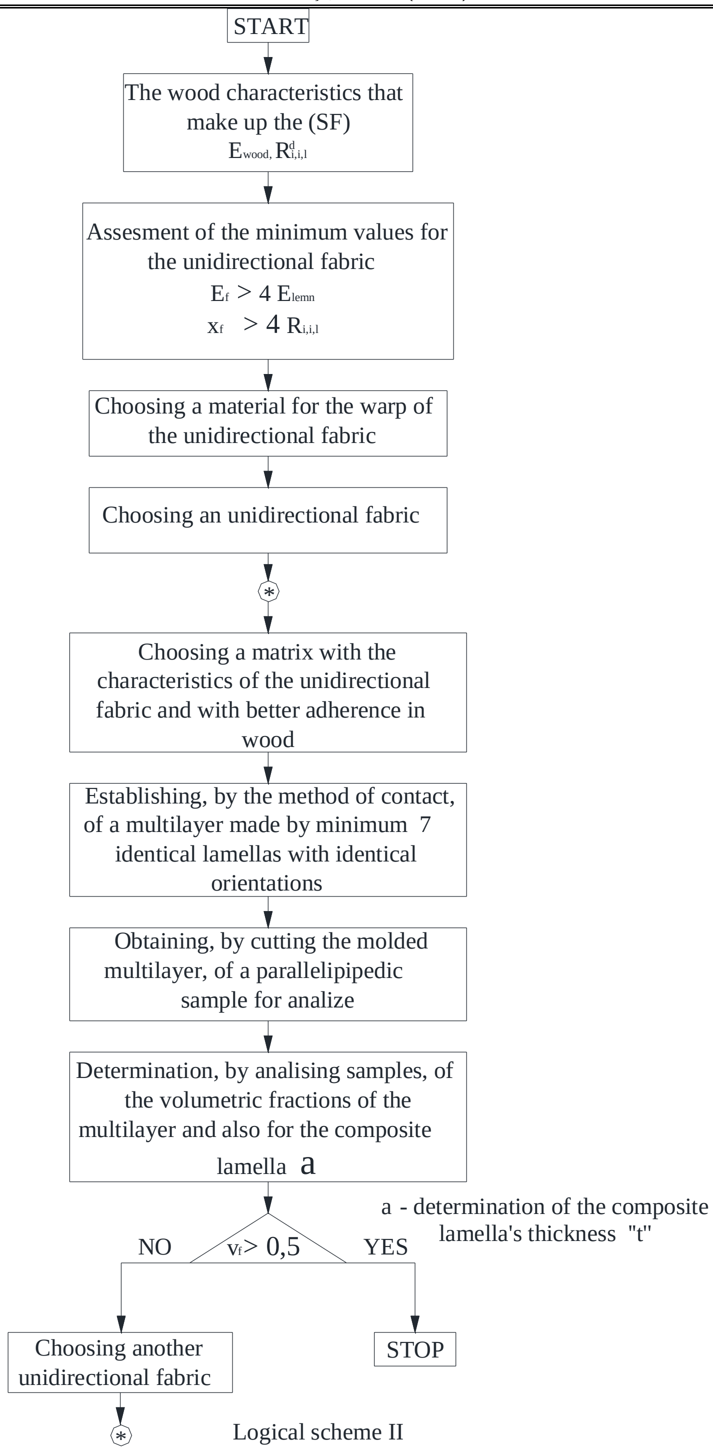
The inequalities of the logical Scheme II have their theoretic support in Secu & Roşu (2013).

4. Pre-Dimensioning of Strips Made of Composite Multilayer

After pre-dimensioning of the lamella, the characteristics of multilayer, of which is necessary for hybridisation, are known.

At this stage, the objectives of the design engineer are the following:

a) selection of the group of beams belonging to the (SF) which imply hybridisation on certain areas, (MGH);



Logical scheme II

b) determination, for each partial hybrid beam, of the thickness of the multilayer and its length (the width of strip is, due to economic reasons, the width of beam, and the position of the composite multilayer on the section is made on the tensioned fibre in order to avoid losing stability).

The determination of the (MGH) implies:

i) computation of the “ff” structure;

ii) highlight, on every beam, the maximum capable bending moments (in the mid - span and in the support) and of the allowable vertical displacement;

iii) verification, for each beam, of inequalities:

$$M_{r,i} \le M_{r,i,\text{cap}};\ M_{c,i} \le M_{c,i,\text{cap}};\ v_{z,i} \le v_{z,i,\text{adm}},\ (i \in \overline{1,n}), \tag{1}$$

where: $M_{r,i}$ is the maximum bending moment, on support, of beam; $M_{r,i,\text{cap}}$ – capable bending moment, on support, of beam i; $M_{c,i}$ – maximum bending moment, in the field, in the beam i; $M_{c,i,\text{cap}}$ – capable bending moment, in the mid-span, of beam i; $v_{z,i}$ – maximum vertical displacement, of beam i; $v_{z,i,\text{adm}}$ – vertical, admissible displacement, of beam i; $i = \overline{1,n}$; n – number of beams belonging to (SF).

The i beam on which at least one of the inequalities (1) is not satisfied belongs to (MGH).

A beam belonging to (MGH) can be in one of the following situations:

a) only $M_{r,i} > M_{r,i,\text{cap}}$;

b) only $M_{c,i} > M_{c,i,\text{cap}}$;

c) only $v_{z,i} > v_{z,i,\text{adm}}$;

d) combinations of the first three cases.

In case $M_{r,i} > M_{r,i,\text{cap}}$, the determination of the thickness of the composite strips, h_{pc}, implies the following stages:

a) the section on the bearing is hybridised with the strip of b width and h_{pc};

b) the hybrid section is changed into equivalent section (h_{pc} – remains constant; $b_{elpc} = b(E_1/E_{wood})$; in which b_{lpc} – the equivalent wood width of the composite strip; E_1 – the main elasticity module – along the warp’s threads – of the composite stratification);

c) the relations (2) are written on the equivalent section with $M_{r,i}$

$$\sigma_{x,1}\frac{E_1}{E_{\text{wood}}} \le X_t;\ \sigma_{x,2} \le R^d_{i,i,l};\ \sigma_{x,3} \le R^d_{i,c,l}, \tag{2}$$

where: $\sigma_{x,1}$ is the maximum tensile normal stress of the composite strip; x_t – tensile strength, along the warp’s threads, of the composite strip; $\sigma_{x,2}$ – maximum tensile normal stress, of the wood; $\sigma_{x,3}$ – the normal, maximum, compressive tension in the wood; $R^d_{i,c,l}$ – compressive strength, from bending, along the wood fibres, which has the computed value.

h_{pc} is determined using the relations (2) and the thickness of the lamella t.

For this case, the length of the strip, l_p, results from the relation:

$$l_p = 2l_a + l_{r,M_x \geq M_{\text{cap}}}, \quad (3)$$

where: l_a is the anchoring length of the strip (l_a = 30t); $l_{r,M_x \geq M_{\text{cap}}}$ – the length in the area of the support on which the bending moments M_x are higher, equal to the limit, with the capable moments of the wood beam.

In case $M_{c,i} > M_{c,i,\text{cap}}$ the proceeding will be similar and l_p results from the relation:

$$l_p = 2l_a + l_{c,M_x \geq M_{\text{cap}}}, \quad (4)$$

where: $l_{c,M_x \geq M_{\text{cap}}}$ is the length in the area of the span on which the bending moments M_x are higher, equal to the limit, with the capable moments of the wood beam.

In case $v_{z,i} > v_{z,i,\text{adm}}$ the determination of the thickness h_{pc} and of the length l_p on the static scheme and with the loads in Fig. 1 is proposed.

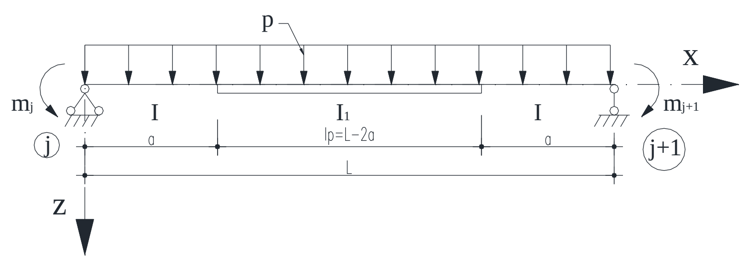


Fig. 1 – The static scheme and the loads for predimensioning from case $v_{z,i} > v_{z,i,\text{adm}}$.

In Fig. 1 the notations represent: p – the load on the i beam of "ff"; j and j + 1 nodes (SF) between which the i beam is positioned; moments m_j and m_{j+1} from computation of structure "ff", values accepted also for determination of displacement of the beam i in "ff"; I – moment of inertia of the beam i in "ff"; I_1 – moments of inertia, equivalent in wood, of the transversal sections in the hybrid area; a – length of the edge area (areas) (with the "ff" characteristics); L – 2a – length of the hybrid area (with the inertia moment I_1).

Pre-dimensioning of h_{pc} and l_p implies the following steps:

a) choosing an economic thickness $h_{pc} = kt \leq 4$ mm, $k \in |N^*$;

b) choosing $b_{pc} = b$;

c) determination of the moment of inertia (equivalent in wood I_1) (I – was determined in the computation of "ff");

d) computation of the vertical displacement, $v_{z,f_{ig1},L/4}(L/2)$ vertical (according to z direction) on the static scheme and with the loads in Fig. 1, with $a = L/4$, in the middle of the opening;

e)comparison between $v_{z,f_{ig1},L/4}(L/2)$ and $v_{z,\mathrm{adm}}$ and the identification, by means of successive iterations, of the final value for h_{pc} and l_p.

In case of combinations between the three cases, solutions are provided in Secu & Roşu (2013).

5. Obtaining the Equivalent Form

The equivalent form, "fe" is obtained from "ff" through the transformation of the elements (MGH) from the beams with hybrid portions in wood beams with variable moments of inerta (the equivalency is performed through the transformation of the width of the composite strip of b in b_{elpc}).

6. Stages of the Resolution of the Structure Computation "fe"

Obtaining "fe" represents just a stage in the algorithm of design (SF) with continuity in nodes and hybrid portions.

The completion of the algorithm implies the following stages:

a) computation of the "fe" structure; practically, as a consequence of the small thicknesses of the composite strip the same loads from "ff" can be accepted;

b) the verification of the general rigidity and of each bar for "fe";

c) verifications of the carrying capacity for the "fe" collumns and for the beams which do not belong to (MGH);

d) verifications of the carrying capacity, also at the level of the tensions, for beams which have hybrid portions;

e) assessment of the reserves localisation and of the rigidity, carrying capacity and normal tensions obtained with "fe";

f) in case of the existence of some reserves, it will be continued by means of an iteration in which some hybrid portions will reach "fe(-1)";

g) iterations continue as "fe(–i)" or "fe(+i)" $i \in |N^*$, until the verifications are fulfilled and the local interventions correspond from an economic point of view.

7. Conclusions

The introduction of a hybrid area of the beam within the spatial frame (SF), with nodes continuity, upgrades the structure from strength and stiffness points of view.

At the computation level of the new structure it is necessary to order and make an algorithm which is based on structural engineering, on the wood particularities, on the legacy of the composite multi-layer and the collaboration of the materials which comprise the hybrid areas.

The algorithmic presentation of the design constitutes the necessary systematisation for resolving these types of structures.

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ALGORITMUL DE PROIECTARE AL CADRELOR DIN LEMN CU CONTINUITATE ÎN NODURI ŞI PORȚIUNI HIBRIDE
Cadre destinate clădirilor de locuit

(Rezumat)

Proiectarea cadrelor din lemn cu continuitate în noduri şi porțiuni hibride (lemn – platbande cu stratificate compozite) este complexă ca urmare a utilizării celor două materiale, a alcătuirii structurale şi a iterațiilor necesare convergenței soluțiilor.

Lucrarea propune algoritmul de proiectare al acestor structuri şi cuprinde următoarele etape: forma fixă, predimensionarea lamelei şi platbandei compozite, forma echivalentă, iteraţii ale formei echivalente.