Environmental Safety House Analysis with regard to the structural behavior of wooden construction

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Abstract— Sustainability is a contemporary source of several technical and organizational solutions, which provides realization of environmental safety construction development. There are a lot of enterprises initiatives coming toward the sustainable construction promoting in Italy in the frame of environmental safety construction technologies. Italian construction follows the best practices on safety wooden houses practices. The article is interesting because it shows that the structural behavior described in the introduction is due in fact to the rotational behavior of the joint, and not to other dissipative effects (friction in various parts of the structure). The effects described in the introduction are in all cases experimentally observed coupling (curve enveloping non-linear change of stiffness reloading). The curve is symmetric since only the behavior of the joint it is shown.

Keywords—sustainable development, wooden construction, friction, multifibre beam, open source software, Code Aster

I. INTRODUCTION

Sustainable development is defined as a practice of the environment protecting through constant improvement of human living standards, what is possible owing to an invention and an innovation which are success keys. Invention and innovation for sustainable development isn’t just about developing new technology, but includes new processes and new ways of solving old problems - creative thinking is the rubric [2]. Invention stimulates entrepreneurship and overall economic activity. In this meaning, invention means a focused application of the human mind to the world that yields an original creation with practical use. Innovation, as defined here, is the practice of bringing inventions into widespread usage, through creative thinking, investment, and marketing.

That’s why basic invention is typically needed to spur innovative activity. To stimulate invention, education should be the centre of action because invention requires a lot of knowledge.

Invention is a set of interactions between human creativity, technology and the marketplace what leads to economic indicators increase.

Society increasingly imposes a challenge for changing the nature of economic activities in almost every sector of the economy. This structural, long-term reorientation and transformation of economic activities is termed a transition [3].

Construction industry need such a transition, because this sector as a user of energy and materials creates waste and this sector uses about 25% of the wood and produce sulphur oxides. Progress in the sustainable development applying is useful for construction sector what is seen in the benefits and organizational solutions. The best practices in the sustainable construction can be built up only by an effective transfer of knowledge and experience, which can creates the competitive position of the industry on the worldwide marketplace. Transition of knowledge and experience into technical and organizational solutions is created through several kind of actions, which can includes e.g. cluster initiative or creating other network kinds such as associations or technological platform. Italy goes through an economic phase of transition which started in 1992 and it is characterized by [4,5]:

- restrictive policies in public expenditures, set to reduce the great public debt,
- accumulated during the Eighties,
- constant effort of industry to achieve higher productivity rates, as their main strategy in order to participate in the global exchange market.

There are three fundamental issues of a sustainable development strategy in Italy which concerns protection of ecological systems, production growth and environmental damage and change of economic objectives from quantitative growth to qualitative development. Central and Northern part of Italy is a settlement of a large number of small and middle companies. The construction sector is fundamental for the Italian economy. Research reveals that, over the past five years, a few key drivers (legislation, certification, active role of trade associations and green building clusters) have increased the interest and demand for green building products and services in Italy. Currently, best prospects for the Italian green building market include:

- photovoltaic panels (for domestic use),
challenge for green builders in Italy is compliance with the
Energy, the Environment and Buildings
issues in Italy was the publishing in 2004 of a

The level only now.

starting to be implemented in a uniform manner at the national
Italian legislation that regulates green building, which is

buildings 

saving and of the application of advanced solar technologies in
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technologies, the development of renewable sources of energy,

Document
purpose of the document was to demonstrate benefits on
energy consumption regulating in building. Document
highlighted how building envelopes in Italy generally are
usually not energy efficient because of the lack of adequate
thermal insulation, especially for those buildings constructed
before a 1976 law that set heating guidelines.

II. RESEARCH INITIATIVES ON ENVIRONMENTAL
CONSTRUCTIONS ANALYSIS

Among the various strategies of government intervention
capable to stimulate further progress towards sustainable
development are the activities of research and development led
at the present time by ENEA in the sectors of environmental
technologies, the development of renewable sources of energy,
of innovation of product and especially in the fields of energy
saving and of the application of advanced solar technologies in
buildings [4].

Some research results concerns not only technologies but
also renewable resources used for green building. In Italy the
common opinion about wooden houses is that they are
expensive, their behavior in seismic regions is basically
unknown, they are very unsafe in case of fire, besides, their
behavior over time is not known and therefore not guaranteed.

Since some years Province Trento commissioned a research
to Dolomiti Pro Group about wooden houses with the aim of
understanding the behavior of such a building after an
earthquake and after a fire. Dolomiti Pro Group is partecipated
by Duplo Costruzioni, Ille Prefabbricati and Benedetti
Sistemi. After such research, it's high time to broaden such
research and to go deeper with mathematical models. Software
side of the research are be led by Tyto company, which is a
partner of Dolomiti Pro Group.

Wooden buildings are frequently associated with energy
saving houses, and because of the not brilliant economic
situation in Europe, it's a good moment to push researches
about energy saving topics, what means:

– to make research grow,
– to increase the 'green mood' in population and, in the mid-
long term,
– to increase a new economy based on wooden and energy
saving buildings.

Such trend is already visible in the Northern part of Italy all
along the Alps, were average temperature is lower and
nevertheless, where good weather (and direct sun, for
photovoltaic panels) is available very for most of the days in a
year.

It's time to let the research to be lead by open source
software tools: open source software made giant steps in
quality and in the variety of its application fields. Open source
software is typically led by a community of programmers and
users, and its incubation is frequently situated in some
Universities, what means a very quick way of sharing
knowledge and both problems and solutions. It means it's the
ideal situation for research in general (and specifically for our
research).

For such research partners of Dolomiti Pro Group decided
to use Code_Aster [10], a finite elements software written by
EDF (Electricité de France, first energy producer in Europe)
for internal use. It comes to be a huge development and study
environment, with applications in statics and dynamics,
mechanical and hygro-thermal analysis, with a large possibility
of non linear computations. To give an idea of such a project,
it's documentation covers more than 20000 pages! Moreover,
Code_Aster is completely free and open source.

A complete description of Code_Aster features is out of the
topics of this paper. However, a first application to the seismic
behaviour of a wood panel under cyclic loading is shown. This
is the first step for characterizing the seismic behaviour of a
structure or of a structural element. In fact, if it is true that
dynamics effect are not included, on the other hand the
displacement or force levels are controlled. From the
numerical point of view, the static cyclic analysis allows
 calibration of model parameters, to be used eventually in a
second step in a dynamical analysis.

To study a wooden house behavior in case of
earthquake is rather different than study the behavior of
a concrete building in the same situation. Concrete
differs from wood in weight and in the elastic law they
follow. Frame follows a different behavior due to totally
different technique about joints and other aspects. The
study started from experimental data about nail
deformation due to an earthquake, what can be seen in
Fig. 1.
Then it can be seen a behavior law in Code Aster for plastic hinges. This law had to give a very good approximation of the experimental data of Figure 1. It has to be underlined the fact that the law draws many cycles, widening on an on, both right and left, to simulate the irreversible deformation of the nails in the joints in the wood (Fig. 2).

Then starting from a sample earthquake we used the preliminary model with an automatic calibration feature of Code Aster for tuning parameters based on experimental data reconstructed. The calibration program has executed hundreds of times the earthquake calculation to find the most suitable parameters to describe the experimental data (Fig. 3).

In the previous research, a building 1:1 scale was built and tested against 3 different earthquakes. Test was conducted upon a full 'dressed' 3 floors building, it means with furniture inside.

Further steps are scheduled in future: the first one is to test a building with water and sanitary system fully operative: there is no available data about such a test situation so it is natural to understand what happens, there is a big interest on it about the companies. A wall was tested against fire to understand what happens to physical parameters of the wood. Next step the research tries to understand and predict the thermal behavior of a wooden building after an earthquake. To test a thermal behavior on a wooden building it's necessary to have a complete building (1:1 scale or smaller) and to blow smoke into the building at a certain pressure, if the smoke is visible immediately outside it means that there is a crack in the walls.

Further tests will try to check what happens after an earthquake on a the thermal insulation system of a building: If smoke is visible after an earthquake test and such smoke was not visible earlier, it means that earthquake solicitations damaged the building in the frame, or in the nails or in the walls. Tests on wooden buildings were shortly described as if they were so easy and cheap to complete: instead, there must be a great organization to get information from these test, just consider the need of sensors or the need of all the infrastructure to simulate the earthquake or the fire.

So far, all researches pointed their attention to an existing building. But so many doubts arise when the all were dealing with the health of a wooden house after 10, 30, 50, 100 years since its construction, and the idea behind is very simple: if we think about a concrete house, all the historical knowledge makes us so confident that a well build construction will last for long time, let's say a century.

And there were reported two centuries old wooden buildings in Russia and Portugal to compare research results. The problem is that the construction procedures have changed so much, and there is no idea about modern wooden buildings behavior, just think about air pollution or wood mildew. So common opinion keeps are very suspicious about such buildings.
In next step of our research authors would like to point our attention to what happens to a wooden building over time. Wood is a natural element, so it interacts with humidity and its environment in a much more active way than concrete can do. Wood reacts to weather changes, humidity changes, temperature changes. Since it's a living matter it may adjust its position over time in a much different way than a concrete building may do. The idea of a further research about behavior over time comes out of here. The authors have to deal with historical data about the 'matter wood', its behavior with weather changes over time. Just imagine the seasonal changes, or the daily changes, and after collecting all data we need to build a mathematical model with Code Aster to predict what happens to wood, or what happens to nails-wood combination, or what happens to wood-concrete combination close to the foundations.

III. PLASTIC HINGES

The model refers to a wood, panel-type constructive system of Ille Costruzioni, consisting of a load bearing structure of beams and columns completed by the internal wall having both a stiffening function against horizontal forces and a partitioning function [6]. The Ivalsa institute performed for Ille Costruzioni some experimental cyclic tests on the described panels. Increasing levels of an imposed displacement were applied on the top of the panel, shown in Figure 1a. The same displacement level was applied with alternating sign (from left to right and from right to left). Each level of imposed displacement was repeated three times. The response of the panel in terms of applied force-displacement of the upper beam is shown in Figure 5b (blue curve).

Figure 5b shows that the structural behavior is strongly nonlinear and dissipative. It may be described in a qualitative manner by means of the following characteristics:
1) A curve obtained for the same load level (same displacement level, applied in the two opposite directions) is symmetrical about the origin for positive and negative displacements.
2) The enveloping curve (which contains the maxima of the cyclic curve) is non-linear, tangent stiffness decreasing with the level of displacement.
3) Reduction of stiffness for the same level of displacement imposed from the second reloading. Let’s call \( DX \) the \( i \)-th imposed displacement, and denote by \( n = 1,2,3 \) the number of repetition \( DX^n_i \). It can be observed clearly that the curves \( DX^2_i \), \( DX^3_i \) coincide and that the branch load \( DX^1_i \) retraces the entire curve \( DX^3_{i-1} \).
4) Comparing a branch of load with the subsequent reloading, \( DX^1_i \) and \( DX^2_i \), is observed in parallel with the overall loss of stiffness in \( DX^2_i \) that in reality the force level reached is virtually the same.

Other similar tests have been made on other types of frame, more traditional, represented in Figures 6 and 7. In particular, we reported the case of a frame with asymmetric stiffeners (Fig. 6) and of a symmetrical frame (Fig. 7). Consequently, the structural response to cyclic loading respect to the origin is decidedly asymmetric respectively in the first case and approximately symmetrical in the second case. The cycles characteristics (apart from the symmetric/asymmetric property) are those already listed before.
IV. PREVIOUS MODELLING (DRAIN)

Previous modelings at Ille Costruzioni used the finite element program DRAIN, developed at the University of Berkeley. DRAIN specializes in frames, also with non-linear constitutive laws. In addition to beam elements of traditional type, multifibre beam elements can be used, or joints with linear or non-linear behavior. Among the latter, an example is given by the law of Figure 4, developed in [8] and implemented in DRAIN. DRAIN is a finite element software dedicated to linear and non-linear analysis in civil engineering. Applications are exclusively for frame (columns and beams) structures.

For the frame of Figure 5a, beams and columns were simply given a linear elastic behavior, while the structural non-linearity is attributed to the nodes, and modeled with plastic hinges [5]. Plastic hinges are joints with a plastic moment-curvature behavior, similar to that of Figure 8 but in terms of moment-rotation. As for the simulation test of Figure 5, the numerical results are compared to those experimental data in Figure 5b (red curve). You will notice the following characteristics of the model compared with the experimental results:

- the model is calibrated on the power level of the last cycle, nevertheless fails to follow the curve tangent enveloping with descending order (item (2) of the initial list : “enveloping curve”),
- differences between $DX^1_i$ and $DX^2_i$, described in paragraphs (4), are not reproduced,
- the experimental unloading branch is not reproduced correctly.

With reference to the initial list, only the characteristic (1), “symmetrical curve”, is correctly reproduced. It would be interesting to analyze the results in terms of energy dissipation, which is an important parameter under a seismic point of view, and that with a first impression seems quite correct (amplitude of the cycle).

As for the simulation tests of Fig. 6 and Fig. 7, the model used is able to reproduce the variation of stiffness to the reloading (items (3) - (4) in the list : “reduction of stiffness” and “comparing a branch of load with the subsequent reloading”), but the amplitude of the cycle (and so the dissipated energy!) is much lower than the required level. The
items (2) cannot be verified. The symmetrical/asymmetrical character (item (1), the latter is correctly reproduced.

V. AVAILABLE MODEL IN CODE ASTER

In Code_Aster a joint type (discrete element) modeling is available, with various types of constitutive laws (viscous, plastic, etc). The wooden frames can be modeled by using plastic hinges, obtained with a discrete element with a plastic behavior on rotation. The law of behavior is called in Code_Aster "DIS_ECRO_CINE", and is applied to a discrete element of zero length (a law of the same type, with different parameters, can be applied for all 6 degrees of freedom of translation and rotation).

![Example of DIS_ECRO_CINE law used in Code_Aster on the rotation around the z axis (MFZ = moment, DRZ = rotation).]

The details of the law are described below. Form of the elasto-plastic law:

1. elasto-plastic relationship:

\[ F = K_e (U - U_{an}) \]  

(1)

2. plastic criterion:

\[ f = (F - X) - F_y \]  

(2)

3. kinematic hardening:

\[ X = \frac{K_x \alpha}{\left(1 + \frac{K_x \alpha}{F_y} \right)^{\frac{1}{n}}} \]  

(3)

where:

- \( K_e \): elastic stiffness
- \( F_y \): elastic limit
- \( K_x \): kinematics stiffness
- \( F_u \): asymptotic force
- \( n \): power

In total there are 5 parameters; \( \alpha \) stands for the plastic deformation. The law of behavior is shown in Fig. 9. There are 6 curves depicted, a reference curve (yellow, "MAT_REF" in legend) of parameters:

\[ K_e = 3200000 \; ; \; F_y = 2500 \; ; \; F_u = 1400 \; ; K_x = 850000 \; ; n = 2.25 \]

and other 5 curves with each one parameter changed from the reference curve is shown below in the parameter value close to the name of the curve given in the legend of Fig. 9:

- MAT_LIMU (red curve): \( F_y = 2000 \)
- MAT_KCIN (gray curve): \( K_x = 600000 \)
- MAT_PUIS (brown curve): \( n = 1.25 \)
- MAT_KE (green curve): \( K_e = 2500000 \)
- MAT_LIMU (red curve): \( F_u = 1800 \)

It can be already seen that the characteristics of the numerical curve:

- the reloading is made on the same branch of the load curve,
- with increasing rotation, it tends to an asymptote of the moment,
- the unloading is elastic, the stiffness equal to the initial stiffness and intensity equal to two times the elastic limit \( 2F_y \).

Ultimately, we can already see that the law at present in Code_Aster, as for the law already in use in Drain, does not yet have all the features needed to reproduce the experimental data.

Retracing the observations made for Figure 5b (in the introduction with p. 2) with the characteristics made to Figure 5, we can say that the characteristic (2) (enveloping curve tangent with descending) may be reproduced, but they will never the characteristics (3) and (4). With regard to the symmetry with respect to the origin (point (1)), the behavior can only be symmetrical.

VI. RESEARCH RESULTS OBTAINED WITH CODE ASTER

We tried to simulate the test [8] using our model in Code_Aster. The structural model corresponds to a frame (two beams and two pillars in a closed square configuration and simply supported). At each intersection of beam-column a plastic hinge is inserted (4 in total). The central panel was not modeled.

The tensile strength and stiffness are calibrated by hand directly comparing the response of the numerical simulation to the experimental curve. We have then:

\[ K_x = 5 \cdot 10^{10} N \cdot mm \]
\[ F_y = 8 \cdot 10^6 N \cdot mm \]

The other parameters were obtained for inverse analysis, using the algorithm of Levemberg-Marquardt, available through the automatic calibration command MACR_RECAL of Code_Aster.
As for the elastic properties of the wood, the Young's modulus is equal to 15000 MPa. The curve obtained is shown in Fig. 6.

\[ F_u = 3 \cdot 10^7 \text{ N} \cdot \text{mm} \]
\[ K_x = 1.3 \cdot 10^9 \text{ N} \cdot \text{mm} \]
\[ n = 2 \]

It should be noted that the structural behavior of "asymmetric" is clearly due to the diagonal stiffeners in wood, and not riveted joints. To obtain the structural response correct then it would be necessary to model them, so as for the central stiffening panel.

VII. PERSPECTIVES

There are other studies that focus on the behavior of single joint rather than on the structural response [9]. These authors report experimental curves on riveted unions, and a model that describes the coupling in an explicit way (Fig. 11).

VIII. CONCLUSION

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Code Aster is able to describe, in a single software environment, what happens to a wooden building over time.
Researchers didn’t mention the possibility to study acoustic behavior, or thermal dissipations, for example. Another field of research is to follow what in France is already exists in behavior, or thermal dissipations, for example. Another field of CO₂ over all the lifecycle of the building from construction to demolition. As it was said earlier, in France it is a common practice, and the results of such a document are able to determine the interest of a potential customer and, of course, the final price of the building.

References