Additional Design Requirements of Steel Commercial Greenhouses in High Seismic Hazard EU Countries

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ADDITIONAL DESIGN REQUIREMENTS OF STEEL COMMERCIAL GREENHOUSES IN HIGH SEISMIC HAZARD EU COUNTRIES

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1. ABSTRACT

Steel greenhouse structures of commercial production are to a significant extent designed and manufactured, as far as the countries of the European Union are concerned, in the Netherlands, Italy and Spain (and to some extent also in France). Evidently, these countries differ in seismic hazard, a fact well depicted in the relevant loading combinations within EN13031.01. Hence, the structural efficiency of a steel greenhouse designed for low seismicity is strongly doubted, and the need of additional design requirements is due, so that such a structure could be officially accepted as adequate and installed in areas prone to strong earthquakes. The present work tackles the aforementioned problem in a systematic manner, offering well - established design solutions oriented from standard steel design practice. These, if adopted, may lead to a unified approach, without alternations of

geometry and connectivity of the most common types of steel commercial greenhouses in Europe. The effectiveness of the proposed strengthening solution is demonstrated via a case study, regarding a Venlo type glass - covered steel greenhouse, originally designed in France and imported to Greece through Italy.

2. INTRODUCTION

Greenhouses are highly sophisticated structures that contain unique structural and functional characteristics, aiming at providing ideal conditions for satisfactory plant growth and production throughout the year. A well-designed greenhouse must maintain all the important climate factors as close as possible to desired optima and hence it is required to allow high light transmittance, low heat consumption, sufficient ventilation efficiency, adequate structural strength and good overall mechanical behaviour combined with low construction and operation costs. All the above features have been systematically reviewed by von Elsner et al. [1,2] for greenhouses in European Union countries. In these works, both the design requirements and typical designs of greenhouses in Europe are presented, the local factors influencing their variation are analysed and the importance of the development of a European Standard for greenhouse design, towards a unified approach for construction regulations, is pointed out.

This Standard, namely EN13031.01 [3], was formally issued and published in 2001, providing rules for the design and construction of commercial production greenhouses. Since galvanized steel is one of the most commonly used materials for greenhouse construction (especially in areas where wood is expensive), the aforementioned Standard together with Eurocode 3 [4,5] and Eurocode 8 [6] provides a global platform for the design of steel greenhouses in particular.

Among EU countries, Italy, the Netherlands and Spain (and to a certain extent also France) are the major designers and manufacturers of various widely used types of steel greenhouses [1]. Their high quality and very competitive price make them a price-performance commercial product, which cultivators in EU countries often directly import from their original source. However, the climatic, terrain and seismic conditions vary significantly between these countries (and even between different areas of each individual country) and hence it is quite unlikely that a steel greenhouse originally designed for a country of low seismicity is structurally acceptable – in conformity with the aforementioned Standards – for installation and use in areas prone to strong earthquakes.

To address this problem, the present work offers a unified approach for meeting the additional design requirements for earthquake resistance of steel greenhouse structures, without altering their geometry and thus maintaining all their other functional aspects. The proposed approach is based on standard steel design practice, follows well-established additional bracing techniques and may serve as a tool for the development of a much more systematic treatment of the structural efficiency of typical steel greenhouses within the European Union, regardless of their design origin and installation target. Finally, its efficiency is demonstrated via a case study regarding a Venlo-type glass-covered greenhouse imported to Greece from Italy, but designed according to French specifications and with no knowledge whatsoever whether seismic loads were taken into account, even for Italian conditions.

3. PROBLEM STATEMENT AND PROPOSED APPROACH

3.1 Typical European steel greenhouses and their bracing system

According to standard engineering practice concerning single-storey steel buildings of high flexibility and regularity in plan in both principal directions, as typical commercial production greenhouses (for more details see [1] and [2]), the only way of providing adequate earthquake resistance is to design these structures using a bracing system that can function properly for both seismic and wind actions. Nevertheless, since the structures dealt with must provide (a) maximum clear area for plant cultivation and (b) minimal obstacles inside spans and also in the transverse direction, the bracings can only be installed on the sides and the roof, in a manner not obscuring ventilation openings, not decreasing light transmittance and so that their presence acts also in favour of, or at least against, permanent installations and often required hanging crops. In the sequel, *it is of major importance to explore the bracing system of widely used steel commercial product greenhouses* made in Italy, the Netherlands and Spain (for reasons mentioned in the Introduction), *seek whether these systems may also provide adequate resistance to earthquake loads, and if not propose solutions not affecting the overall geometry and therefore performance of the greenhouse*. Some typical design plans of Italian, Spanish and Dutch greenhouses are depicted in Figures 1-3 respectively, while special attention is given on the famous Venlo type "glasshouse", originated from Holland (but manufactured also in other EU countries), and the schematic picture of which is shown in Figure 4.

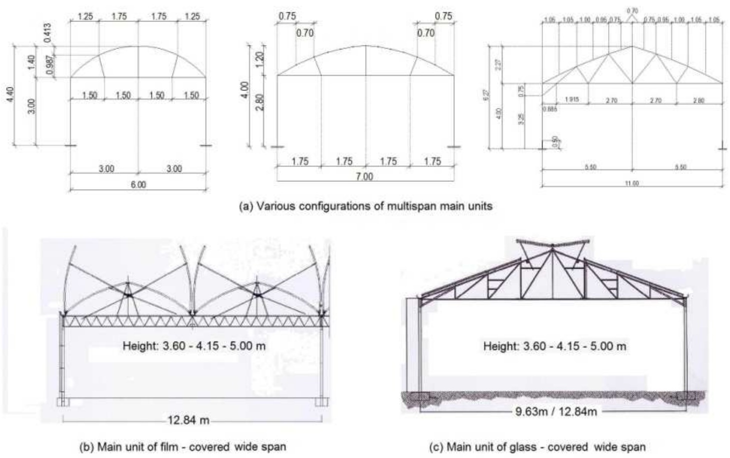


Fig.1: Typical designs of Italian steel greenhouses

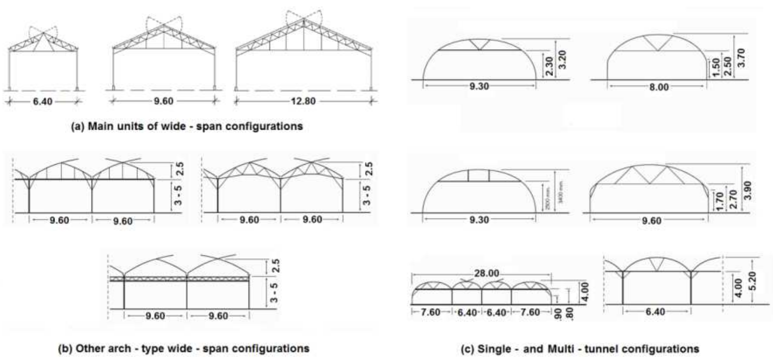


Fig. 2: Various Dutch steel greenhouse configurations

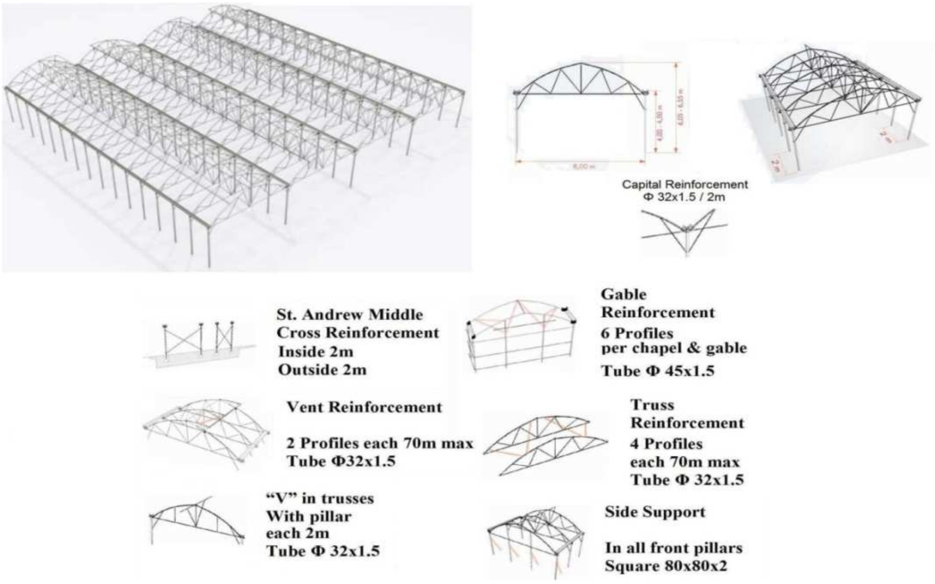


Fig. 3: Typical design of a Spanish steel greenhouse extremely resistant to wind and snow

All the above Figures are representative but not exclusive, since a variety of forms and configurations is also available in the market, as for instance the Almeria type Spanish greenhouse as well as other Multi-Span, Multi-Gothic and Multi-Tunnel types (for cold, moderate and warm climates), which are not shown herein for brevity. All these however are accompanied by a minimal bracing system, capable of withstanding along with the main load bearing capacity units wind actions and gravitational loading, while, to the knowledge of the authors, none of these forms are developed with transverse vertical bracing, known to provide resistance to lateral loads in this direction.

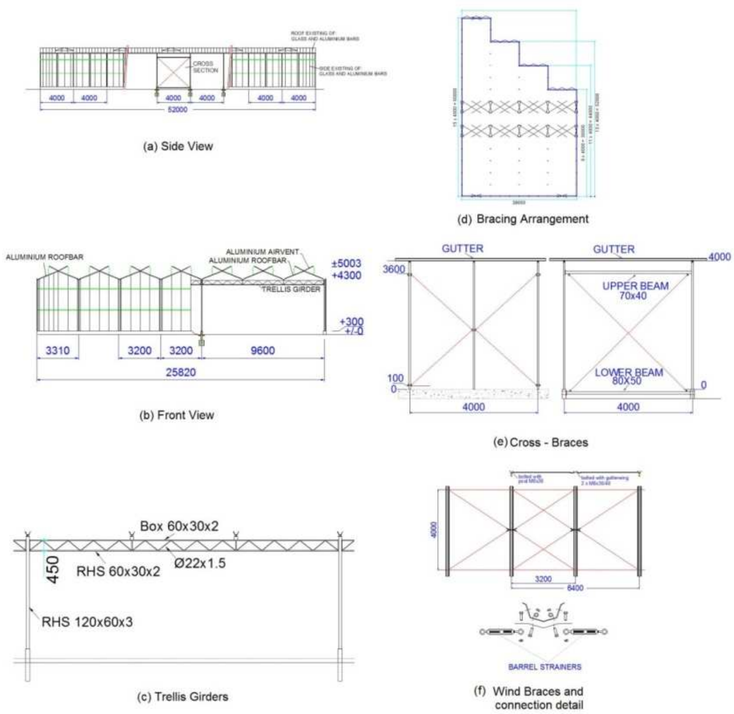


Fig. 4: Typical drawings of a Venlo-type glass-covered greenhouse structure

Same comments apply for the Venlo-type greenhouses, and moreover one may observe that their bracing is tension only, with some pretension, depending on the level of the applied loads.

3.2 ULS combinations for seismic actions in EN13031.01 and EC8 provisions

According to the Ultimate Limit State (USL) combinations that include seismic actions, according to EN13031.01, only three countries, namely Germany, Greece and Italy, must account for earthquake loads in the analysis and design of greenhouses. The relevant provisions are given in the contents of Table 1:

Combination ID	**Permanent actions**	**Permanently present installation actions**	**Snow actions**	**Crop actions**	**Seismic actions**
d1	G_{k1}	G_{k2}	-	$\psi_{2Q3}Q_{k3}$	$\gamma_{AE}A_{Ek}$
d2	G_{k1}	G_{k2}	$\psi_{2Q2}Q_{k2}$	$\psi_{2Q3}Q_{k3}$	$\gamma_{AE}A_{Ek}$
ψ: combination coefficients, γ: partial factor (for their values/country see EN 13031.01)					

Table 1: EN 13031.01 ULS combinations for seismic actions

In addition to the above, according to EC8, all gravity loads must be accounted for in the determination of the mass of the structure, and in the sequel in calculating the equivalent lateral seismic loads, acting at the top of the supporting columns on the sides (in both directions). Hence, the percentage of the snow mass to be accounted for should be equal to the corresponding value of ψ_{2Q2}, and in the same manner the crop mass should contribute to the overall mass of the structure proportionally to the value of ψ_{2Q2}, where applicable. Torsional effects must also be considered, which implies a very efficient bracing system.

3.3 Proposed solution methodology

In order to enhance the load bearing capacity of steel greenhouses, not designed for earthquake resistance, so that these become able to withstand seismic actions, and thus to be adopted for use in the target EU country of high seismic hazard, the following steps are proposed:

(a) Analyze the structure under the combination containing seismic loads, i.e. d1, d2 were applicable, accounting for the local conditions of the target country.

(b1) If the structure fails, identify the weak areas, apply additional braces or change the bracing system, and if required (without change in structure dimensions) apply larger cross-sections or better steel quality to groups of members. Repeat step (a) until efficiency is reached.

(b2) Offer more than one solution regarding the bracing system and overall changes.

(b3) Contact the original manufacturer and find out which of the proposed solutions may be readily constructed (accounting for any new type of connections) and also available without severe additional cost.

(b4) If step (b3) does not lead to an accepted solution abandon the possibility of using the specific type of greenhouse. If step (b3) is successful proceed to step (c).

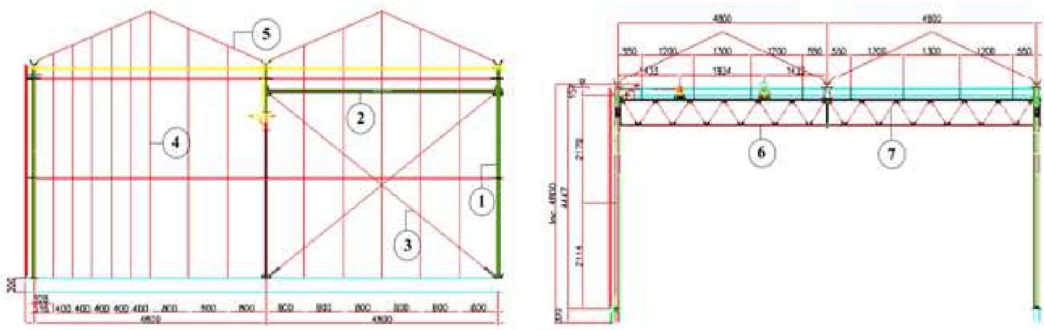
(c) Continue with the analysis of the original structure, in case step (a) does not lead to failure, or with the qualified newly designed structure according to step (b3), under all ULS (and if required also under all SLS) combinations. If efficiency is reached, the goal has been achieved. If not, maintain the new bracing system and change steel quality in member groups and/or choose larger cross-sections etc. until efficiency is reached.

(d) For all the above steps, do not “worship the least weight God”.

Evidently, there is no magical recipe involved in the whole scheme. Some general rules of steel design practice are of course in order, but engineering judgment in conjunction with the versatility of the original manufacturer will also play a very important role, while the final choice will rely on the cultivator in the target EU country.

4. A CASE STUDY

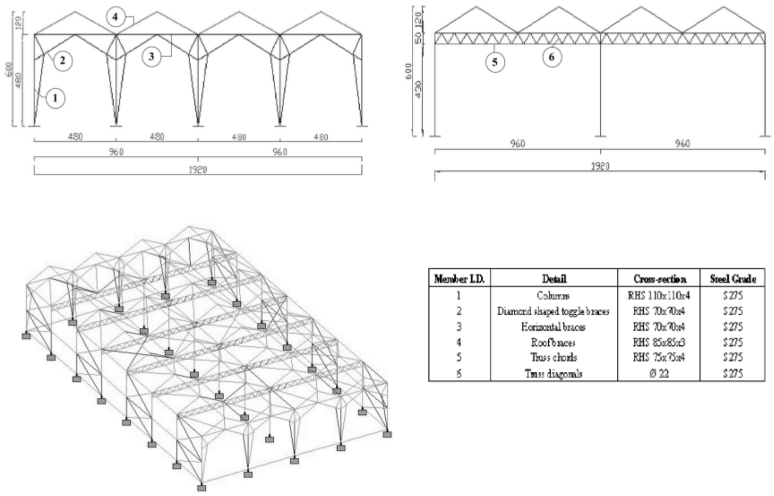
The proposed step-by-step method, in its worst scenario, is demonstrated via a case study, which concerns a Venlo-type glass-covered greenhouse, imported in Greece through Italy, but originally designed according to French standards. At this point it should be noted that the drawings and calculation details available were minimal, which is quite common in these situations, especially if the target market is not that attractive to the manufacturers (a “take it or leave it” well-known policy). The design drawings of the structure that were available to the authors and the Greek importer are shown in Fig.5. All modifications were performed by the authors for clarity, since French technical vocabulary was present throughout. Cross-sectional properties are also shown in this Figure in tabular form.



Member I.D.	Detail	Cross-section	Steel Grade
1	Columns	RHS 120x60x3	S235
2	Horizontal braces	RHS 140x140x3	S235
3	X-braces	Ø 12	S235
4	Aluminium braces	Equivalent Steel section used	-
5	Aluminium roof braces	Equivalent Steel section used	-
6	Truss chords	RHS 60x30x3	S235
7	Truss diagonals	Ø 14	S235

Fig.5: Design drawings of the original structure of the case study

Afterwards, the steps described above where performed; the original structure under earthquake loading for Greek provisions showed premature lateral-torsional buckling of columns as well as excessive yielding of trellis-girder members at the connections with the intermediate vertical supports. After various redesign efforts, only one feasible restructuring was achieved, depicted in Figure 6. Diamond toggle braces were adopted for the front and rear sides, and the new design did not affect all other required features. From the contents of this Figure it is more than profound that a major redesign was required, leading to a rather non-economic structure. The original manufacturer was contacted, but was very reluctant in co-operation; as a result the project was abandoned.



Member I.D.	Detail	Cross-section	Steel Grade
1	Columns	RHS 110x110x4	S275
2	Diamond shaped toggle braces	RHS 70x70x4	S275
3	Horizontal braces	RHS 70x70x4	S275
4	Roof braces	RHS 85x85x3	S275
5	Truss chords	RHS 75x75x4	S275
6	Truss diagonals	Ø 22	S275

Fig.6: Schematics of the new, earthquake resistant structure of the case study

5. CONLUDING REMARKS AND SUGGESTIONS FOR FUTURE TASKS

The proposed scheme is simple and may serve as a starting point – fuse for future European research. It is suggested that a major effort should be undertaken, with participation of all interested parties, towards a uniform design of steel greenhouses, leading to the realization of a Trans-European Grant.

6. REFERENCES

[1] VON ELSNER B, BRIASSOULIS D, WAAIJENBERG D, MISTRIOTIS A, VON ZABELTITZ C, GRATRAUD J, RUSSO G and SUAY-CORTES R "Review of Structural and Functional Characteristics of Greenhouses in European Union Countries: Part I, Design Requirements", *Journal of Agricultural Engineering Research*, Vol. 75, No. 1, 2000, pp. 1-16.

[2] VON ELSNER B, BRIASSOULIS D, WAAIJENBERG D, MISTRIOTIS A, VON ZABELTITZ C, GRATRAUD J, RUSSO G and SUAY-CORTES R "Review of Structural and Functional Characteristics of Greenhouses in European Union Countries: Part II, Typical Designs", *Journal of Agricultural Engineering Research*, Vol. 75, No. 1, 2000, pp. 111-126.

[3] EN 13031-1, "Greenhouses: Design and Construction – Part 1: Commercial Product Greenhouses", *ECS*, 2001, Brussels.

[4] EN 1993-1-1, "Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings", *ECS*, 2005, Brussels.

[5] EN 1993-1-8, "Eurocode 3: Design of steel structures – Part 1-8: Design of joints", *ECS*, 2005, Brussels.

[6] EN 1998.01, "Eurocode 8: Design of structures for earthquake resistance – Part1: General rules, seismic actions and rules for buildings", *ECS*, 2004, Brussels.

ΕΠΙΠΡΟΣΘΕΤΕΣ ΑΠΑΙΤΗΣΕΙΣ ΣΧΕΔΙΑΣΜΟΥ ΧΑΛΥΒΔΙΝΩΝ ΘΕΡΜΟΚΗΠΙΩΝ ΠΑΡΑΓΩΓΗΣ ΣΕ ΧΩΡΕΣ ΤΗΣ ΕΥΡΩΠΑΪΚΗΣ ΕΝΩΣΗΣ ΜΕ ΥΨΗΛΗ ΣΕΙΣΜΙΚΟΤΗΤΑ

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ΠΕΡΙΛΗΨΗ

Τα χαλύβδινα θερμοκήπια παραγωγής στην Ευρωπαϊκή Ένωση σχεδιάζονται και κατασκευάζονται ως επί το πλείστον στην Ολλανδία, την Ισπανία και την Ιταλία (και σε κάποιο βαθμό στη Γαλλία). Οι χώρες αυτές διαφέρουν αισθητά σε σεισμικότητα, γεγονός που αποτυπώνεται στους συνδυασμούς φόρτισης του EN13031.01. Συνεπώς, η δομική ακεραιότητα ενός θερμοκηπίου σχεδιασμένου χωρίς την πρόβλεψη σεισμικών φορτίων είναι ιδιαίτερα αμφισβητήσιμη, με αποτέλεσμα να προκύψουν επιπρόσθετες απαιτήσεις σχεδιασμού και ενίσχυσης, προκειμένου μια τέτοια κατασκευή να καταστεί αποδεκτή για λειτουργία σε περιοχές υψηλού σεισμικού κινδύνου. Η παρούσα εργασία αντιμετωπίζει το πρόβλημα συστηματικά, μέσω ευρέως αποδεκτών λύσεων σχεδιασμού χαλύβδινων κατασκευών. Οι Αυτές μπορεί να οδηγήσουν σε μια ομοιόμορφη προσέγγιση του θέματος, χωρίς την ανάγκη διαφοροποίησης της γεωμετρίας και της συνδεσιμότητας των πιο κοινών τύπων χαλύβδινων Ευρωπαϊκών θερμοκηπιακών κατασκευών. Η αποτελεσματικότητα της πρότασης καταδεικνύεται μέσω μελέτης περίπτωσης ενός θερμοκηπίου τύπου Venlo Γαλλικού σχεδιασμού, εισηγμένου στην Ελλάδα μέσω Ιταλίας, ενώ η όλη εργασία συνοδεύεται και από πρόταση για συνολική αντιμετώπιση του όλου θέματος.