Problems and Rudimental Tends on Implementation of European Union's Directives on Sustainable Building

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Over the past few years, several accidents of building structures, which had serious consequences, have occurred. The collapse of Maxima shop in Riga probably caused the biggest resonance in the Baltic States. Such accidents particularly encourage the assessment of saving trends that have recently gained popularity, their assumptions and consequences, especially the long-term ones. (In some cases, the buildings are lifeless even in short random overload cases. The latter is practically impossible to avoid both in construction and exploitation).

Resource-saving trends are highlighted in parallel and at different levels (EU, Republic of Lithuania etc). Special attention is paid to non-renewable resources and their sustainability. It has become an unavoidable necessity in the modern world. It is noted that a construction process is one of the most susceptible consumers to resources and it has many opportunities to save.

In this way, the contradiction between saving resources and reliability of building structures appeared. Lately, it has been one of the most important challenges in the field of construction. Both many practical lessons and modern simulation methods are necessary to solve it.

The publication deals with the saving measures and the possibilities in building practice and the problems that occur. One aims at generalizing the accumulated experience. Objective resource-saving barriers on the base of truss structure design and installation are disclosed and discussed. Possible ways to mitigate these barriers are considered.

KEYWORDS: sustainable building, truss, contradiction, prestressing.

Introduction

Construction is an important branch of the economy and in many ways, a reflection of the economic situation of the country. The EU Sustainable Development Provisions (An agenda 2001) rightly points out that construction is one of the most susceptible economic sectors to resources. Therefore, the saving of resources in the building construction is a particularly important task in terms of economic sustainability (In Lithuania, these tasks are discussed in the acts by the Ministry of Environmental Protection) (NSSD 2011). It is reasonably invited to scrutinize the possible construction options in terms of expenditure. Construction has to respond to the needs of the economy. This publication is also dedicated to these goals.

Lithuanian designers and specialized literature have examined resource saving while constructing various building elements for the recovering of medium-sized spans. Known recommendations, catalogs, especially in the Soviet era and later, were dedicated to summarize the construction experience of rational design of a variety of beams and slabs.

Recently, the demand for large span structures has increased in Lithuania. Orders for such constructions are also received from foreign countries. It is necessary to cover tens of thousands of square meters of space for such constructions. A wide variety of truss structures is used in the world for this purpose. Some of the world's top truss examples are provided in Fig. 1. In terms of resource costs, a truss complex is one of the most economical large span constructions. Their efficiency depends on the conditions in which they are used. Currently, trusses are widely used for covering commercial and social centres.

Some years ago, only some metal trusses were designed. This is especially characteristic for the period when designers turned from the calculations based on the permissible stress to the method based on limit state. Therefore, the truss construction experience is not widespread. The accidents of trusses and their complex that recently happened in various locations in Europe (for example, Riga) promote deeper analysis of such structures, both positive and questionable.

A number of significant sustainable building trends have already been highlighted

Fig. 1

Some examples of trusses, popular in the world
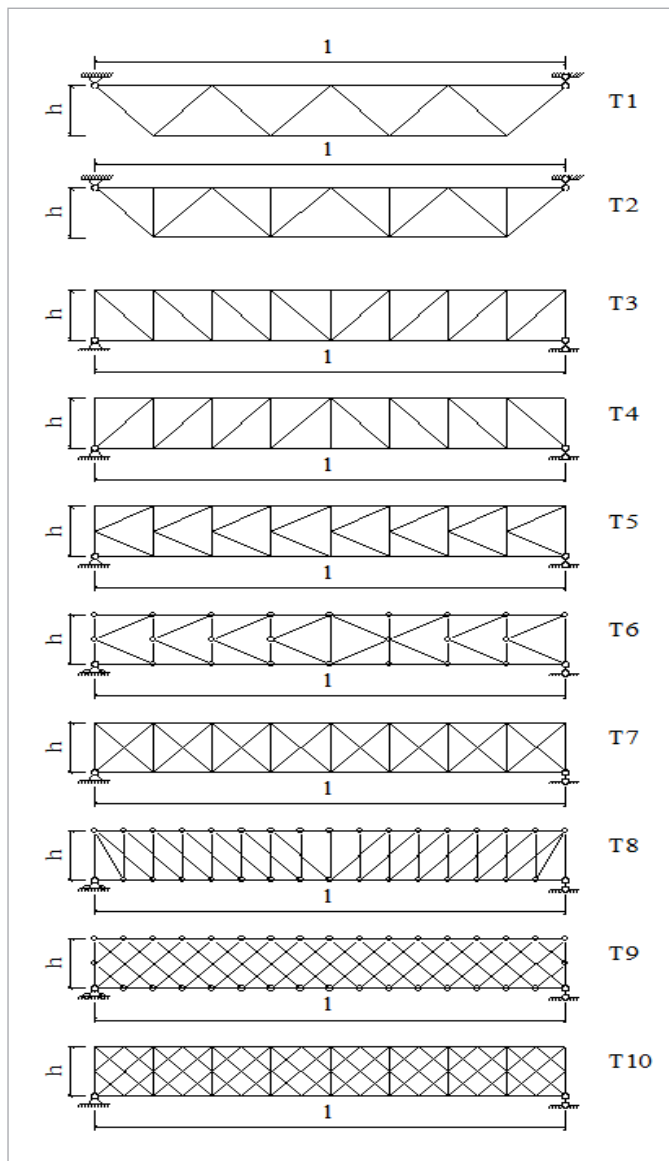
(Kudzys and Juocevicius 2005). One of them is based on the direct practical experience data, collected by the building companies. A large part of that experience is legitimated in norms, regulations, and guidelines. But much material, accumulated in practical experience, is still not reflected in norms and standards. Therefore, it is not always useful for the interested parties. Usually, it is little processed and summarized, and other designers or manufacturers do not know much about it.

In terms of reasonable resource saving, it is purposeful to systematically collect a database on the effective resource saving solutions that are viable during exploitation and were adapted in various scientific design and construction research organizations, as well as to analyze, summarize, and provide practical instructions.

At that point of view, the accumulated experience of the companies "Pramoninis Montazas" and "Pramonines Metalo Konstrukcijos" are worth attention. It systematizes the wealth of material on the usage of metal and metal-wood trusses.

This experience is processed and presented in the form of graphs in the publication and it is analyzed from different perspectives and aspects.

While implementing the EU sustainable building provisions, Lithuania is not always able to use all the appropriate ways and opportunities. The country is not able to produce most of the metal ware, such as metal profiles that are also necessary for the installation of building constructions. It remains the possibility to compose them as inventively as possible, to properly take care of them while exploiting, protecting the structures from premature wear and premises of accident. In such cases, a lot of engineering-economic saving contradictions accumulate. Lithuania itself does not make better resource-efficient production capacity (machinery, equipment and other measures) that is also used for the production of constructions. At best, Lithuanian engineers can only make the use of these capabilities rational.

Therefore, a number of possible saving ways of the resources are not very realistic, when implementing the Environmental Protection Directives of the Republic of Lithuania that concretized the EU provisions in the process of structure design, manufacturing and maintenance (An agenda 2001, NSSD 2011).

In this regard, the experience accumulated by the companies "Pramoninis Montazas" and "Pramonines Metalo Konstrukcijos" is worthy of study, generalization and wider use.

The companies "Pramoninis Montazas" and "Pramonines Metalo Konstrukcijos" have been studying the effectiveness of various trusses. Cultural conditions of installation and maintenance in Lithuania and other foreign countries were taken into account. The gathered information enables business-like advice for clients, offering rational options for the interested parties (Saparauskas and Turskis 2006, Turskis *et al.* 2009). Therefore, the possibilities of cost-saving measures and examples are discussed using the performance data of the companies "Pramoninis Montazas" and "Pramonines Metalo Konstrukcijos". For this purpose, one of the most effective truss design schemes in Lithuania, i. e. trusses with parallel bands, are usually applied. They are mainly used for low-slope roofs. Their assembly is relatively easy. It is noticeable that force distribution in such truss chords and truss web bars is more equally than in many other truss versions. This is important because one aims at the unification of bar cross-sections with a heavy hand. As a result, the industrial production opportunities of the standard metal material appear to be often exploited very uneven. There are significant reserves of resource saving in the improvement of exploiting potential.

The utilization of physical properties of the metal truss bars is very uneven, when all unification provisions of the profiles are followed. These typical uneconomical cases are presented in Fig. 2–4.

Diagrams vividly reveal that the load-bearing capacity of truss bars sometimes is used only a small percentage, which is irrational and uncoordinated (Fig. 2, 3, 4).

Resource-saving opportunities

Fig. 2

Operational part of load-bearing capacity of top truss chord (half of the truss)

Fig. 3
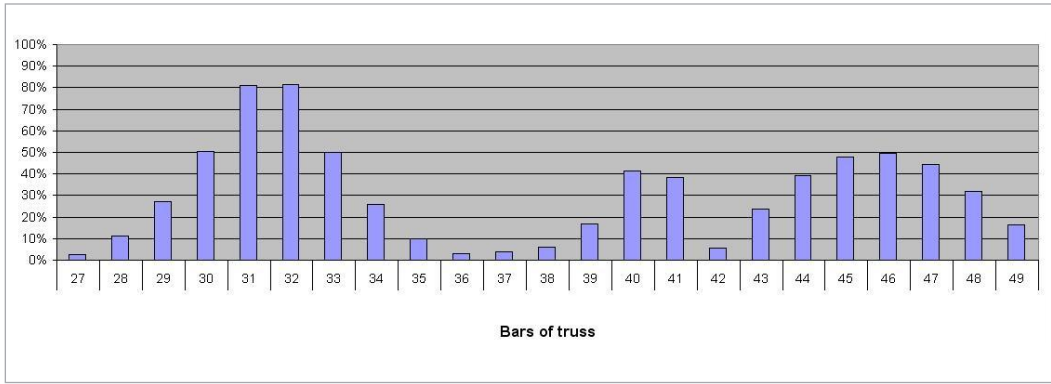
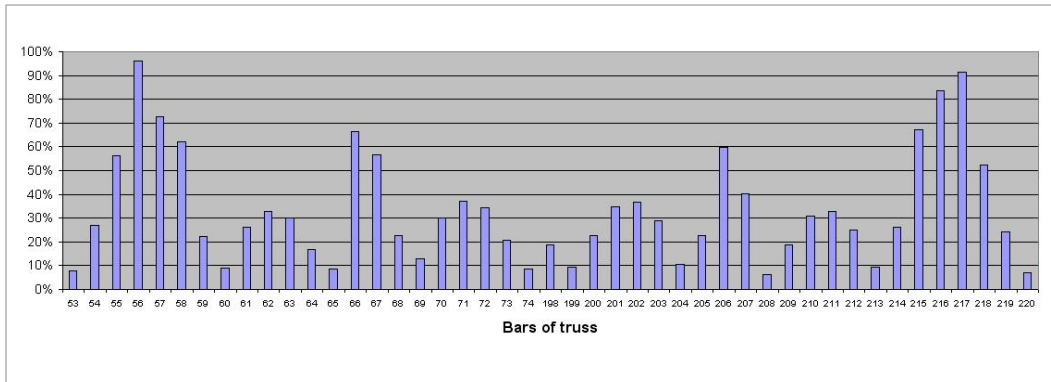Operational part of load-bearing capacity of bottom truss chord

Fig. 4

Operational part of load-bearing capacity of web members (half of the truss)
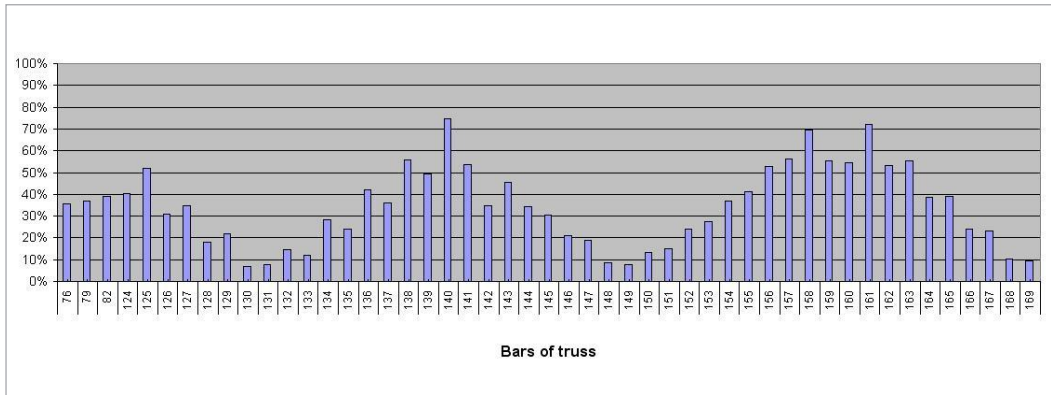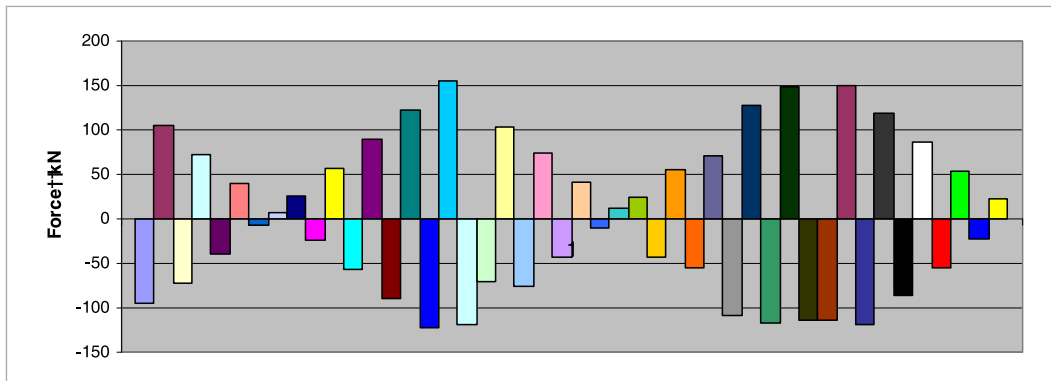

Fig. 5

Force distribution example of web members: up- tension force, down - compression force

The limitations of cross-section use can be effectively mitigated by selecting the appropriate selective prestressing for separate truss bars. The measure aims at smoothing the load-bearing capacity of truss bar cross-sections as much as possible by artificially redistributing stress bars. You have to deal here with the computer task of a variant design.

It is usually impossible to design metal structural members exactly according to the existing stress. On the one hand, this aim is undermined by the strict standardization of metal products. Their nomenclature can not be properly adjusted to the stress, which they have to bear. On the other hand, due to the rationality of manufacturing processes, 2-3 types of elements are usually allowed to use for building structure.

There are several engineering - economic conflicts associated with rationality criteria and priorities of different design-construction and construction - installation works.

One such objection is related to the unification of the truss members on the one hand, and on the other hand, maximum utilization of cross-sectional members (strength of steel). Item unification quite significantly reduces the scale of potential physical-mechanical usage opportunities, and thus the economical use of resources as well (Fig. 2, 3, 4, 5).

The height of latticed structures, including trusses, may be one of the most effective opportunities for economical use of resistance of steel, if one succeeds in maximum leveling of the utilization of bar cross-sections (load-bearing capacity). In this case, the height is considered to be well-chosen. For this purpose, it is necessary to adjust the characteristics of structure stiffness (deflection of the truss plane) and buckling of its elements.

Fuller utilization of potential load-bearing capacity (strength) of the compressed (buckling) bar can be achieved partially by reducing its length. But deflection limits tend to be contradictory.

Deflection of the structure usually starts to increase if there is an attempt to shorten the estimated length of the compression bar in order to maximize the utilization of the potential strength property of the structural material. As a result, the influence of buckling factor for bar bearing capacity is reduced. However, the load-bearing capacity of the construction does not increase; the cost-saving effect necessary for material production is not achieved if you have to reduce the height of the construction for the buckling reduction. It is the assumption of deflection increase. Again, additional material costs are needed for deflection reductions. Thus, the correlation between truss height and its deflection has materially inconsistent value (Janusaitis *et al.* 2003, Keras and Mockiene 2004,2009, Mockiene and Viliuniene 2008).

Contradictory relationship between the deflection and the reduction of structure height (bar buckling) and mass and height is given in Fig. 6-7 (Diagrams are created for trusses T3, T4 pictured in Fig. 1. Nomenclature of rolled products was used for its elements).

The diagrams show that the enlargement of structure height guarantees deflection decrease only in a limited range. Further increase of the structure height is related to the computational gains of
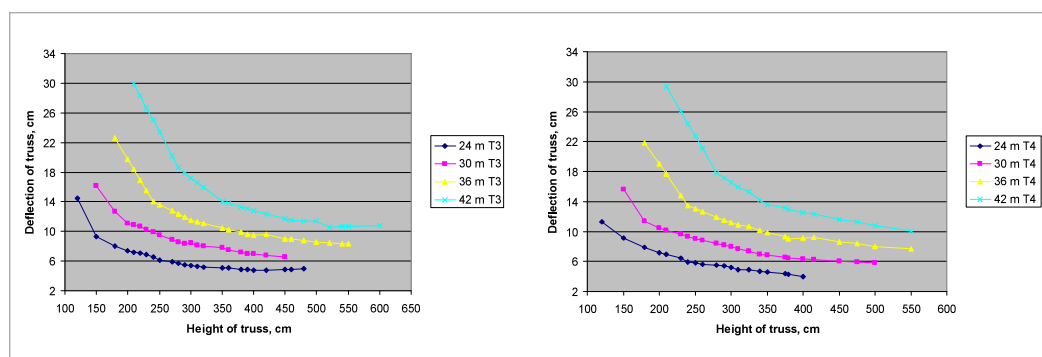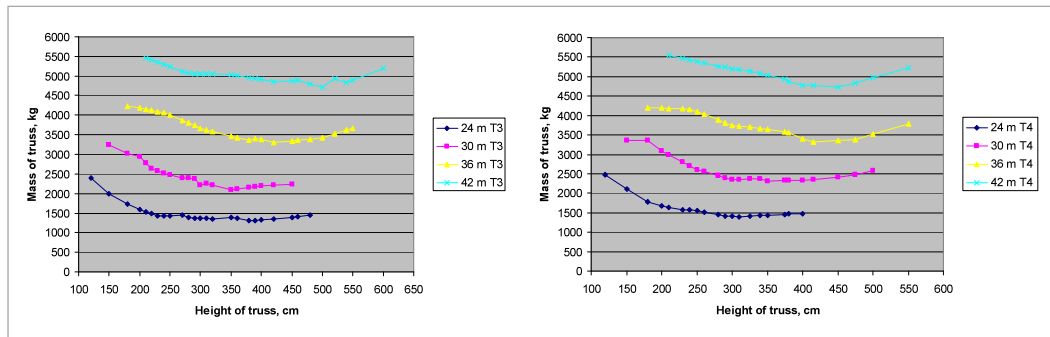

Fig. 6

Relationship between large span truss height and deflection. Loading is given in upper chord nodes

Fig. 7

Relationship between large span truss height and mass

lengths and buckling compression bars and weight gain of bar diameters and constructions. The latter leads to the additional deflection increase (Fig. 6).

Further deflection reduction can be based, for example, on the prestressing of the structure and similar measures, if this requirement is involved in the operation of future space. (It can be acoustic conditions). Prestressing of metal structures and the practical usage benefit forms of the latter are discussed a bit further.

As in many other cases in Lithuanian economy, there are no possibilities to make more efficient production facilities or more universal metal products while building the construction elements. However, there is an opportunity to look for more appropriate construction methods (Subramanian 2010, Farkas and Jarmai 2013, Duggal 2000).

Some part of the collected data about the metal needs for the bearing structures of the commercial and public warehousing roofs are given in Table 1 and graphically in Fig. 8, 9, 10, 11, 12 13.

Table 1

Examined options of large span roof structural solutions, using trusses

Nr.	Area, m^2	Metal consumption kg/m^2	Structural variations				
			Trusses, t	The second order trusses, t	Beams, t	Bracing, t	Heads of column, t
1	812,00	27,058	+	–	+	+	–
2	3240,00	20,576	+	+	+	+	+
3	3942,00	22,912	+	–	+	+	+
4	4096,40	17,543	+	+	–	+	–
5	7270,80	22,955	+	+	+	+	+
6	12305,40	17,058	+	+	+	+	+
7	14192,50	18,235	+	+	–	+	+

Fig. 8

Total weight of roof for various storage facilities, depending on subject area

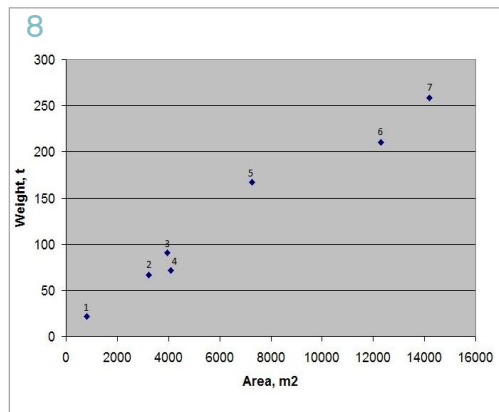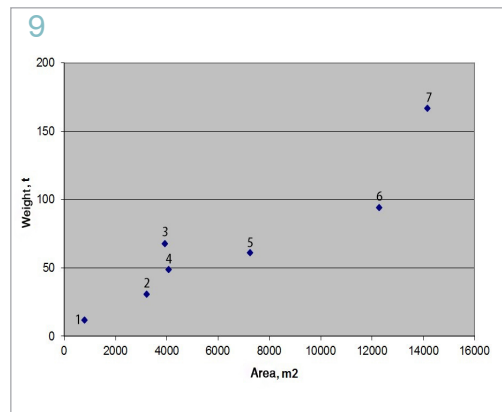Fig. 9

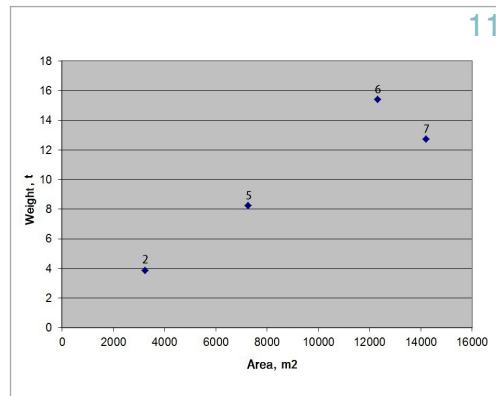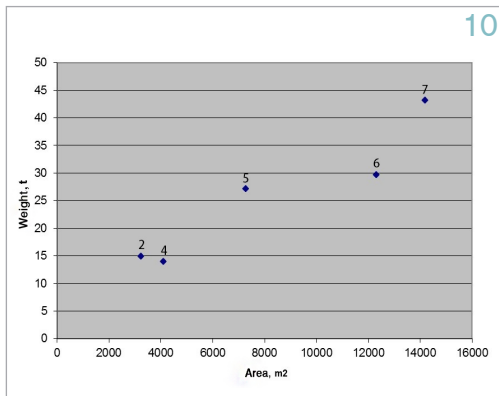General weight changes of trusses, depending on structure of roof

Fig. 10

Total weight changes of the second order trusses, depending on structural solution and covering area

Fig. 11

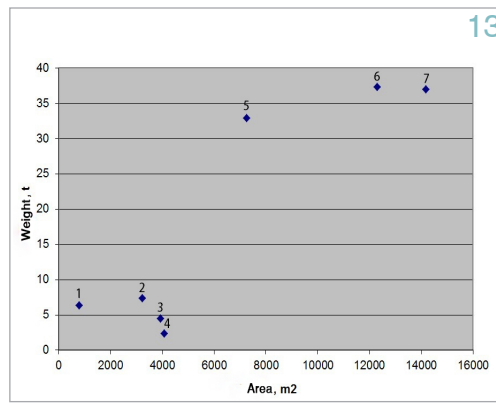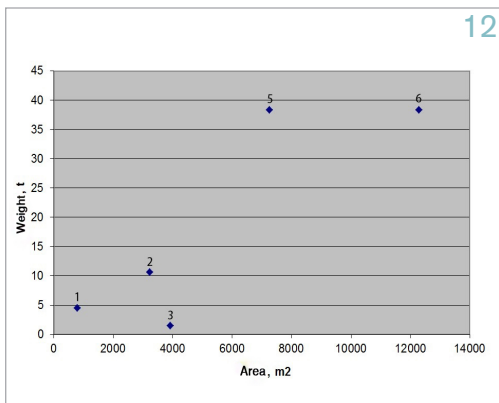Weight changes of heads of column, depending on the structural solution

Fig. 12

Weight changes of beams, depending on the structural solution

Fig. 13

Weight changes of bracing, depending on the structural solution

Figures provided illustrate solution effectiveness of different structures in regard to the metal cost.

While the area of the object increases, the general metal consumption and metal consumption per unit area usually increase as well (Fig. 8). However, there is no reason to suggest that there is an unambiguous dependence of metal costs on the area. The composition of bearing system is equally significant (Fig. 8–13).

In regard to the metal consumption (Fig. 8), the first structural solution is not very successful. In this case, the metal expenditures per covered unit area are the largest (Table 1). The fourth, sixth and seventh structural solutions seem to be quite appealing. The second order trusses are provided for the bearing structure system in recent cases (Table 1, Fig. 8–10).

It is worth paying attention to the metal expenditures of two similar bearing structures of the covered areas. One of these areas is 3942 m^2, the other one is 4096.4 m^2. So, they are similar. The first area is covered without using the second order trusses. In this case, the metal consumption per unit area was 22,9kg / m^2.

In the second case, beams are not used in the roof; meanwhile, the second order trusses were applied. Metal consumption in the latter case was 17,5kg/ m^2. So, the second structural solution allows saving about a quarter of metal expenditures. The main trusses become a bit lighter. Metal expenditure for bracing system decreases (Fig. 13). However, the costs for the second order trusses appear. In general, the larger covering area and spans are, the more useful the second order trusses seem to be (Fig. 10, 12).

Roofing beams were used for the first, second, third, fifth and sixth cases (Table 1). In the second, fifth and sixth cases, they were used in conjunction with the second order trusses. In recent cases,

one succeeded in the reduction of the main truss mass (Fig. 9). The second order truss weight remained similar, and sometimes even less than the mass of the beams (5th and 6th cases, Fig. 10, 12).

In these objects, the second order trusses were used in the second, fourth and remaining cases (Table 1, Fig. 10). Almost in all of these cases, the general weight of the main trusses and the second order trusses used to increase. However, the relative metal expenditures used to become as much as 1 m^2 lower than adopting other decisions.

A properly designed second order trusses or beams can replace part of the necessary bracing and other roofing elements (Fig. 13). Sometimes it is useful to use a variety of combinations of trusses, second order trusses and beams in bearing structure. This is evident from the sixth version of the structural solution (Table 1).

At the same time, when some part of the beams is changed by second order trusses, the costs of time, labor resources, energy, etc. inevitably increase. It is necessary to look for a compromise (for example, the usage of minimax algorithm).

Steel is considered to be the most appropriate and the most common material for the production of the trusses for large spans. However, in the trusses there are, for example, pillars, whose force is equal to or close to zero dashed line in Fig. 14. They are installed when intermediate nodes are constructed, for example, with the aim to make the ranges of the compression chords between nodes shorter and to reduce their computing lengths (Fig. 14). They also provide additional stiffness for the truss.

These elements can be made from weaker and lighter material than steel, such as wood. The postgraduates of the Department of Building Structures of Kaunas University of Technology
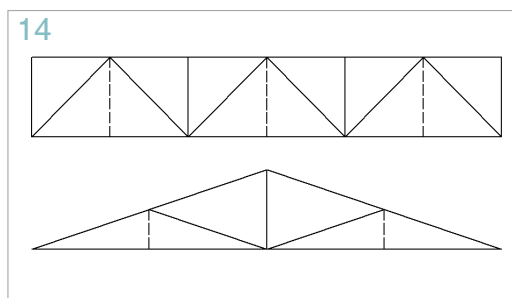

Fig. 14

Examples of composite trusses

- Truss T1
- Truss T1 with wooden members
- Truss T1 with intensified web density
- Truss T1 with reduced height

Fig. 15.
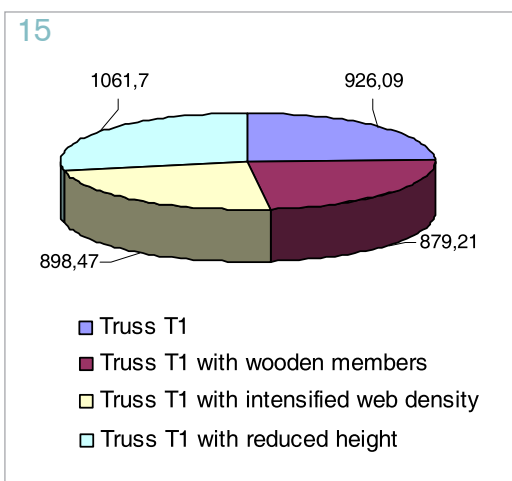
Price comparison of truss manufacturing (Eur)

Fig. 16

Substandard welded joint and developed defects around it

conducted an interesting study, working in the companies engaged in production of building structures. Some noteworthy construction options were offered. The kind of trusses, which were constructed by former postgraduate M. Kasiu-levicius, was used to build the sports palace.

It was observed that a variety of defects, cracks and similar damage can appear in the elements of building constructions. There are various reasons for that: dynamic effects and overloads in the production, transportation, installation of the structure, short-term "force-majeure" overloads during exploitation, long-term development of corrosion processes, etc (Jokubaitis and Jurksa 2002, Parkins and Beavers 2003, Radish and Kireev 2002). The examples of defects of various developments and nature are provided in Fig. 16-18.

These damages change further operational capabilities of trusses (Keras *et al.* 2005, Keras and Mockiene 2005,2007,2009,2010).

Trusses are sensitive structures. Their exploitation opportunities or changes of the conditions may lead to spontaneous accidents, as for example it was in Riga.

Due to metal saving reasons, it is often purposeful to use the so-called prestressing of metal trusses (Fig. 19) or latticed frames (Fig. 20). In this case, the truss members, which should undergo tension stresses during exploitation,

Fig. 17

Micro painting imbalances, which gradually turn to corrosion defects, progress, join together in the micro cracks and macro infringement
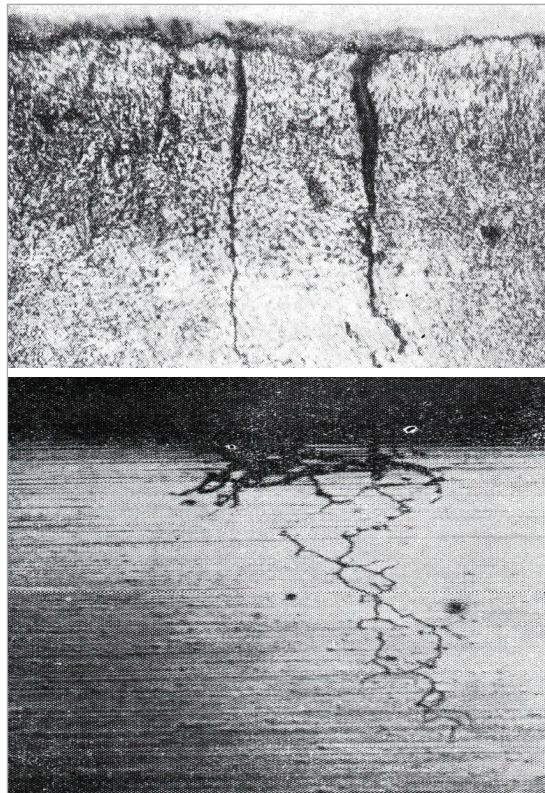

Fig. 18

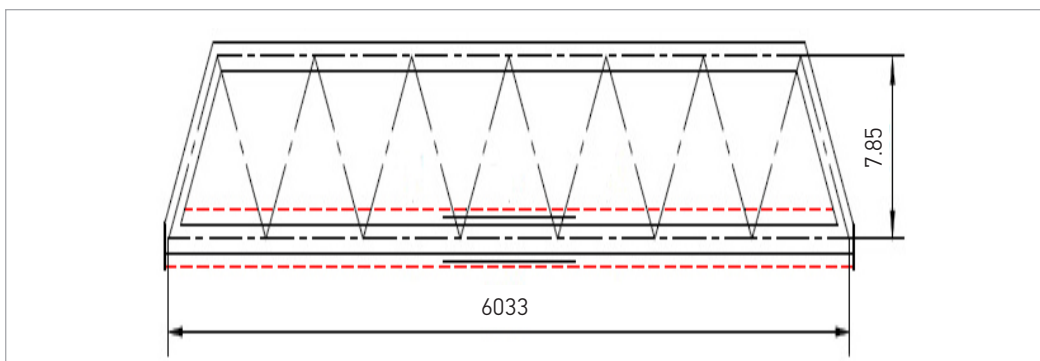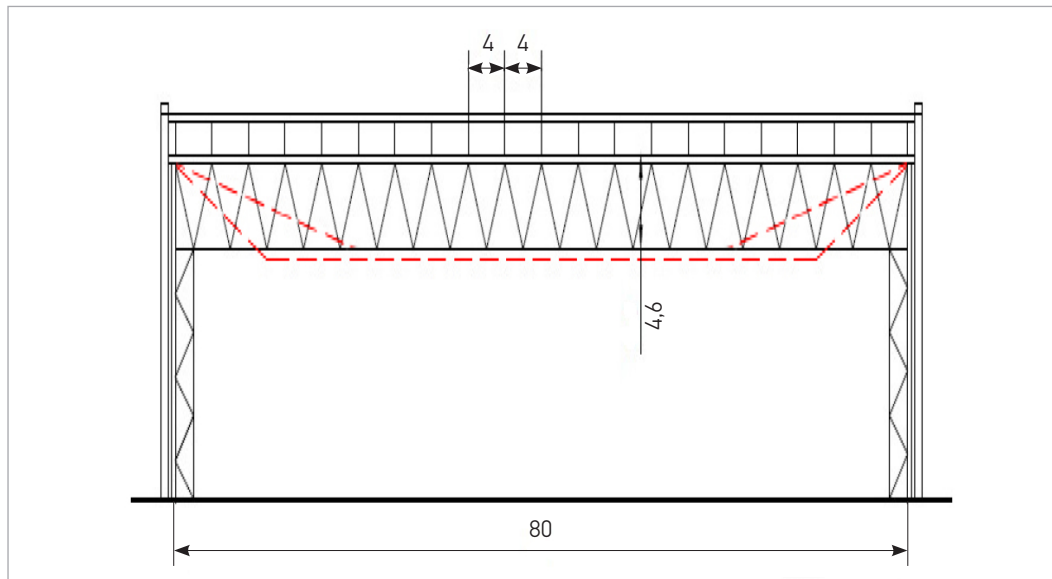Various cracks in steel structures, developed due to corrosion damage, local overloads and other effects

Fig. 19

Example of truss prestressing

are artificially pressed before the start of construction exploitation (Sawant and Vijapur 2013). Typically, it also aims at creation of tension stresses before exploitation in the truss members, in which compression stresses will occur during exploitation. In this way, it is possible to achieve the reduction of the compressive stresses, which occurs during exploitation, by 30%, in half, and sometimes more (Albrecht and Lenwari 2008, Akgul and Frangopol 2004). In this way, trusses are given deflection in the opposite direction than expected from the performance effects. Reduction range is often a subject of discussion. It depends on the geometry of the structure, potential stability of the construction on the truss plane and perpendicular to the plane, giving exceptional reduction from the properties of the metal used in the construction, etc. Usually, the prestressing can be achieved at the integral stresses of 0,5 of future loading members due to exploitation effect. In particular, the reduction range is limited by the construction type, which is provided with the prestressing, and the stability of the truss plane. Then, additional bracing would be required to ensure the truss stability. Additional bracing can increase general cost of roofing structure. So, the prestressing construction becomes not so effective.

Two different prestressing methods have eventually started dominating in the manufacturing practice of building constructions: tension is performed while "resisting" the stand supports or on the same construction.

In the manufacture of reinforced concrete building structures, tension reinforcement at the supports is usually used (in the case of reinforced concrete it is simpler). Then, concrete is put over the tight reinforcement bar. After that, it becomes virtually impossible to adjust the changes of prestressing and stresses of reinforcement bar, which occur in the construction over the time (due to concrete creep, overload of reinforcement relaxation, etc.) (Akgul and Frangopol 2004).

Relaxation and creep processes naturally occur in the produced structures, and eventually they pretty significantly adjust prestressing size, reinforcement stresses and deflections of the structure, etc. However, in this case, reinforcement bars are already bonded to the concrete and it is difficult or impossible to regulate its prestressing.

It is rational to give prestressing for latticed metal structures by means of acting on the same structure directly, leaving the possibility to adjust the prestressing size during the exploitation. These needs may arise due to the long-term metal prestressing relaxation in the strands due to the strand slip in the anchors. In particular, the necessity of such regulation is highlighted and

justified when a construction faces various "force majeure" effects during storms, squalls and a variety of other natural phenomena.

Conclusions

Construction and building companies, research groups, designers of large span structures have accumulated a lot of data based on practical experience. Unfortunately, they are incoherent and not summarized in a reliable and usable knowledge system. Major part of them is not incorporated into the existing standards and guidelines. Therefore, it is important to gradually organize the information.

Currently, there are relatively few data on the economically installed large span building in the long-term exploitation, in particular, when facing unexpected overloads or short "force majeure". Therefore, in terms of reasonable resource saving, it is purposeful to systematically collect database on the effective resource saving solutions that are viable during exploitation and were adapted in various design, construction, and research organizations, as well as to analyze, summarize, and provide it in practical instructions.

Limited product assortment (nomenclature), unification requirements of selective product types, deflection limits of the construction, the risk of bar buckling, strength decline of designed bars in the long term and other factors reduce the chances to fully exploit the relatively high strength of the steel.

Better utilization goals of steel load-bearing capacity may be based on prestressing adaptation to both structures and bars and creative selection and installation of main and secondary bearing structures and similar measures tested in practice.

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