DOI: 10.37105/enex.2021.1.04

ENGINEERING EXPERT

RZECZOZNAWCA

Cause-and-effect analysis of unusual audible sounds in a roof truss structure of a multi-family residential building. A case study.

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Abstract: This paper presents a cause-and-effect analysis of a roof truss structure in a multi-family residential building within the scope of audible sounds described as crackling which intensifies during strong winds. The engineering expert's methodology, including an analysis of the building's as-built documentation and a site visit during which roofing layers were uncovered are also presented herein. The paper identifies and discusses poor roofing workmanship causing the reported adverse effects. Proposals for remedial action to eliminate audible noise in the operation of the roof truss structure are formulated.

Keywords: roof truss, combination of wood and steel, case study.

Please, quote this article as follows:

Sobczyk. K, Andruszczak, M., Cause-and-effect analysis of unusual audible sounds in a roof truss structure of a multi-family residential building. A case study., Engineering Expert, p. 28-34, No. 1, 2021, DOI: 10.37105/enex.2021.1.04

1. Introduction

In recent years, we have seen a continuous development in the construction of new houses (both single-family and multi-family dwellings) [1]. The construction phase is an important stage in the life cycle [2-3] of such a building. During this phase, all building elements with different characteristics, materials and properties, e.g., external walls, internal walls, floor-ceiling assemblies and stairs, are made or built. The roof is one of the most important elements built during the construction phase. The main job of the roof is to protect the building from the elements (e.g., rain and snow) and to shape the building's spatial form. According to [4], the roof comprises a load-bearing structure and a covering. It is also the part of the building that encloses it from above, protecting it from precipitation, wind, ultraviolet radiation, noise and reducing heat loss. Various workmanship errors and physical defects are always likely to occur during the construction phase. In the event of (suspected or actual) damage to the elements part of the structure or improper workmanship thereof are identified, a structural survey detailing the technical condition in order to determine the nature of the problem should be carried out and a ready to use repair procedure should be at hand to minimise any negative consequences [5-6].

The aim of this paper is to present a cause-and-effect analysis of unusual audible sounds in the roof truss structure of a multi-family residential building as a case study based on a technical survey carried out by an engineering expert. Particular chapters represent successive phases of the engineering expert's works [7].

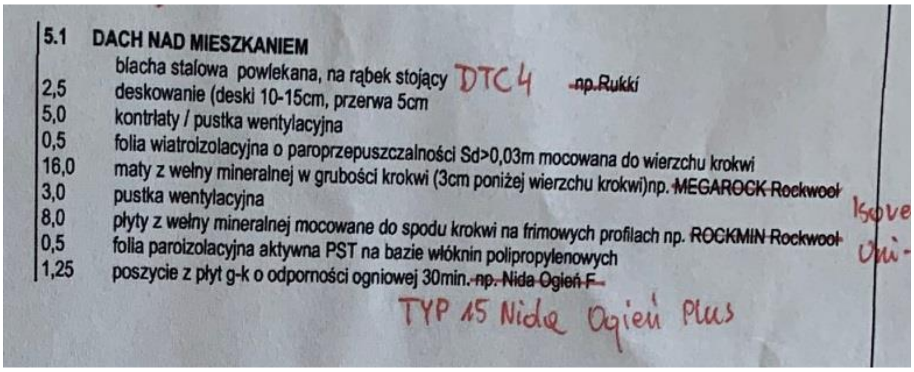
2. Analysis of the available use documentation (including operational documentation)

A report drafted after the last annual periodic inspection of the building was made available for the purpose of drafting this technical survey. The inspection concluded that "the building is used as intended and is suitable for continued use". The technical condition of the building element described as roof structure and covering" was assessed as "satisfactory" following the periodic inspection, Unusual audible sounds in the roof truss structure were not detected during the inspection. The issue was particularly reported to occur on windy days. There is no mention of the prevailing weather conditions in the minutes from the last periodic annual inspection of the building.

3. Analysis of the building's as-built documentation

As-built documentation with handwritten notes and signed by the Site Manager was also made available for the purpose of drafting a technical survey. Changes made by the Site Manager to the Detailed Design Documentation [7] regarding the roofing of a multi-family residential building – the roof consists of the following layers:

- standing seam, coated steel sheet e.g., Ruukki – according to the Site Manager (Fig. 1) DTC4 sheet was installed;
- boarding (10-15 cm planks, 5 cm gap/joint), 2.5 cm thick;
- counter battens / ventilation void, 5 cm thick;
- wind resistant membrane with vapour-permeability of Sd > 0.03 m, attached to the top of rafters, 0.5 cm thick;
- mineral wool batts matching the thickness of rafters (3 cm below the top of the rafters) e.g., MEGAROCK Rockwool – according to the Site Manager's note (Fig. 1), Isover Uni-Mata wool was used;
- ventilation void, 3 cm thick;
- mineral wool slab attached to the underside of rafters on branded profiles e.g., ROCKMIN Rockwool, 8 cm thick – according to the Site Manager's note (Fig. 1) Isover Uni-Mata wool was used;
- PST active vapour barrier membrane based on polypropylene fibres, 0.5 cm thick;
- plasterboard sheathing with 30 min fire resistance. e.g., Nida Ogień F, 1.25 cm thick – according to the Site Manager's note (Fig. 1) TYPE 15 Nida Ogień Plus plasterboard was used.



5.1 DACH NAD MIESZKANIEM

	blacha stalowa powlekana, na rąbek stojący DTC4 ~~np.Rukki~~
2,5	deskowanie (deski 10-15cm, przerwa 5cm
5,0	kontrłaty / pustka wentylacyjna
0,5	folia wiatroizolacyjna o paroprzepuszczalności Sd>0,03m mocowana do wierzchu krokwi
16,0	maty z wełny mineralnej w grubości krokwi (3cm poniżej wierzchu krokwi)np. ~~MEGAROCK Rockwool~~
3,0	pustka wentylacyjna
8,0	płyty z wełny mineralnej mocowane do spodu krokwi na frimowych profilach np. ~~ROCKMIN Rockwool~~
0,5	folia paroizolacyjna aktywna PST na bazie włóknin polipropylenowych
1,25	poszycie z płyt g-k o odporności ogniowej 30min. ~~np. Nida Ogień F~~ TYP 15 Nida Ogień Plus

Fig. 1. Cross-section layers of the building's roof according to the as-built documentation [7].

Documentation pertaining to the steel roof trusses of the building was also provided together with the as-built documentation. This section of the as-built documentation includes the "Details of the erection of the steel roof truss structure" shop drawing. Figure 2 shows a selected element of the connection between a timber rafter and a HEA 160 purlin using two BAT HD15090 angles.

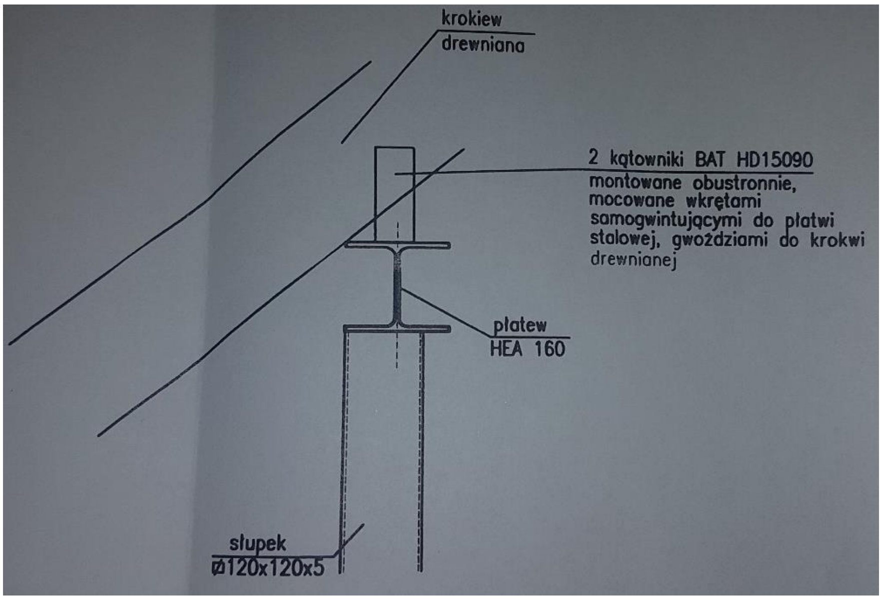


Fig. 2. Element of the connection between a timber rafter and a HEA 160 purlin using two BAT HD15090 angles according to the as-built documentation [7].

4. Site visit

A site visit inspected the building's roof above the dwellings where the owners reported hearing sounds described as crackling, suggesting damage or poor workmanship to the roof truss supporting structure.

Uncovered roof layers of the multi-family residential building were documented on photographs [7]:

a) roof covering – standing seam coated steel roof panel (Fig. 3a);

b) timber battens for a coated steel roof panel (Fig. 3b);

c) counter battens and wind resistant membrane (Fig. 3c);

d) mineral wool (Fig. 3d);

e) timber roof rafter (Fig. 3e);

f) connection point for wooden and steel elements (Fig. 3f).

Fig. 3a. Roof covering – standing seam coated steel roof panel [7].

Fig. 3b. Timber battens for a coated steel roof panel (marked in red) [7].

Fig. 3c. Counter battens (counter batten marked in red) and black wind resistant membrane under counter battens [7].

Fig. 3d. Mineral wool (marked in red) [7].

Fig. 3e. Timber roof rafter (marked in red) [7].

Fig. 3f. Connection point for wooden and steel elements (marked in red) of the roof truss structure. Visible damping membrane between wood and steel at this connection point [7].

5. Irregularities – determining the causes for this adverse phenomenon

An analysis of the available use documentation (including operational documentation) and as-built documentation, as well as the actual state of workmanship of the roofing layers and the roof truss structure revealed during the site visit, found irregularities entailing both direct (without spacers) and careless joining of two construction materials, wood and steel at connection points, and irregularities in the use of wooden battens instead of partial boarding.

I) Issues significant for boarding and battening for tin roofing should be emphasised here. Due to the expanding properties of non-ferrous metal sheets, full boarding is a must if these materials are used. This applies to aluminium, titanium-zinc and copper metal sheets. Partial boarding is acceptable if using standing seam metal roofing panel systems, which mainly contain iron. Fig. 4 shows battens made of timber planks instead of partial boarding under steel sheet roof panels.

Fig. 4. Use of wooden battens instead of partial boarding [7].

II) A drawing showing connection elements of the roof truss structure is included in the as-built documentation for the steel roof trusses of the building (Fig. 2). This detailed drawing shows an element of the connection between a timber rafter and a HEA 160 steel purlin using two BAT HD15090 angles attached to both surfaces, with self-tapping screws to the steel purlin and nails to the timber rafter. Therefore, the as-built documentation indicates that construction elements made of different building materials, i.e., steel and wood, were joined together. The site visit also confirmed these elements were joined directly at roof truss structure connection points (Fig. 5a-b). Such direct “rigid” joining (without the use of elastomer spacers for example) of elements of building materials characterised by different thermal expansion may lead to inconveniences in the operation of the roof truss structure described as audible “crackling”.

a) b)

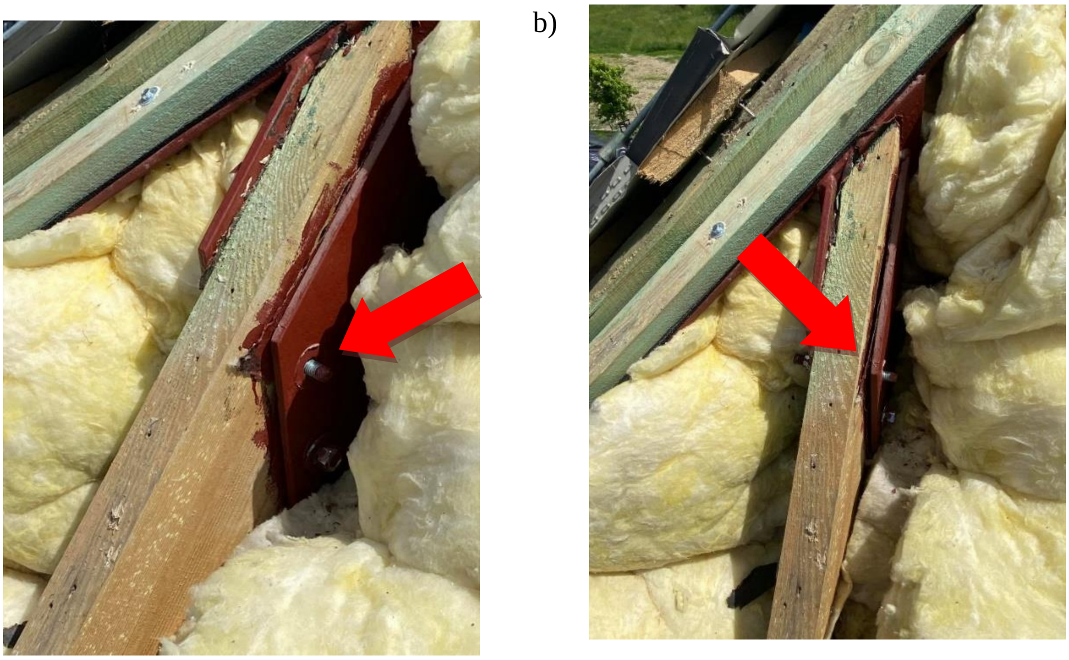


Fig. 5a-b. A solution avoiding direct contact between timber and steel at the connection point is not used. Apparent absence of nuts on bolts (indicated by red arrows) results in loose joints [7].

6. Conclusions

This paper includes a cause-and-effect analysis of unusual audible sounds in the form of cracking which intensifies during strong winds coming from a roof truss structure of a multi-family residential building. The analysis was based on a review of the use documentation and as-built documentation (in particular a detailed drawing of the connection between a timber rafter and a purlin) and a site visit (which included uncovering of the roofing layers). Subsequent chapters reflect particular stages in the preparation of the technical survey by an engineering expert.

The adverse sounds under certain weather conditions (strong wind) were caused by direct (without spacers) and careless joining of two construction materials, wood and steel, at connection points, and the use of wooden battens instead of partial boarding.

Recommendations within the scope of remedial works were as follows (in that order):

- dismantle and scrap the roof covering made of coated steel sheet panels;

- install damping in roof framing structure connection points, i.e., between structural elements made of different building materials such as, steel and timber, by using elastomer spacers to eliminate direct contact between wood and steel for example;

- add narrow planks to the existing roof battens with aim to create a partial boarding;

- re-lay roof covering using new standing seam coated steel panels;

- apply additional soundproofing tape (membrane) fixed to the planks under the centre of each steel roof panel to reduce noise.

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