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Preliminary analysis of Maxima shopping centre in Riga on 21.11.2013

On November **21.11.2013** Maxima shopping center roof collapsed in Riga, Latvia causing deaths and international news. While the rescue work and cleaning of the site is still ongoing, the causes of the collapse need to be studied in detail. This report is an independent attempt to find the cause based on photographic evidence, numerical and analytical calculations.

Based on photographic evidence presented in media, it is obvious that the primary cause for such collapse is the steel truss bolted tension connection. Steel truss, is made out of two pieces, which are assembled on site using bolted connections. The bottom chord tension connection is at least **two** times under-designed. The brittle connection is shown in figures **1** and **2**.

The connection load carrying capacity can be manually calculated using yield-line method or analysed using modern FEM tools as shown in figure **7**.

It can be seen from yield line analysis (figure **4**) and more advanced FEM-analysis, that bolt forces are not evenly distributed. Center bolt is completely useless in load carrying.

The uneven distribution of bolt loads is caused by **well-known prying force phenomena**. **EN 1993-1-8** states: “*Where fasteners are required to carry an applied tensile force, they should be designed to resist the additional force due to prying action, where this can occur*.”

Here the bolts are experiencing prying forces.

Prying forces:

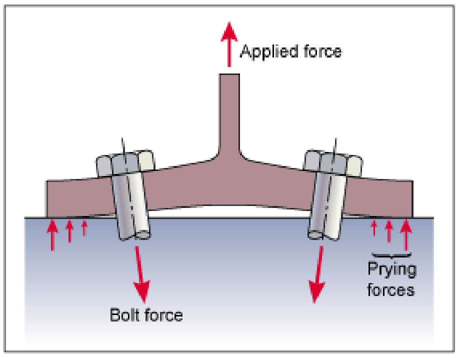

***Figure 1**. Truss bottom chord is connected with end plates and bolts which are in between steel beam flanges. The quantity and sizes of bolts are not sufficient for massive steel beam section. Bolts should also be placed outside of flanges (see figure **5** for example)*

***Figure 2**. Same connection from different angle.*

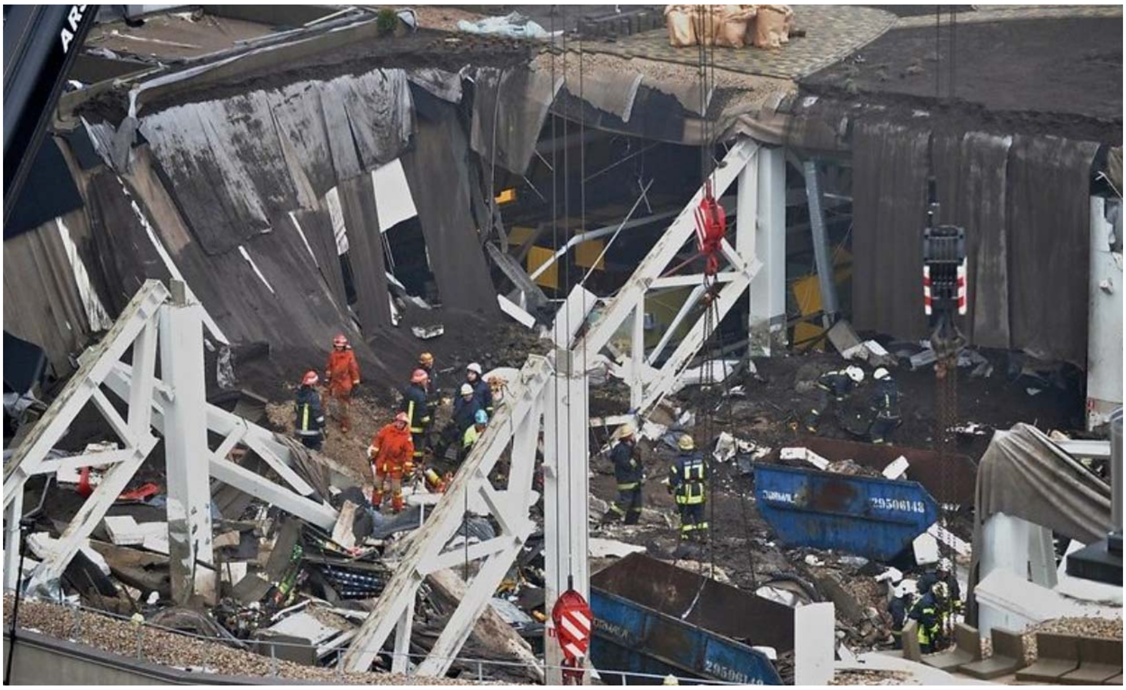

Figure 3. *Steel trusses (**white**) have broken into two pieces and are buried under pile of rubble. The connection in figure **1** and **2** has caused brittle and sudden collapse without any warning. Several other design mistakes are also obvious but of less importance in this case.*

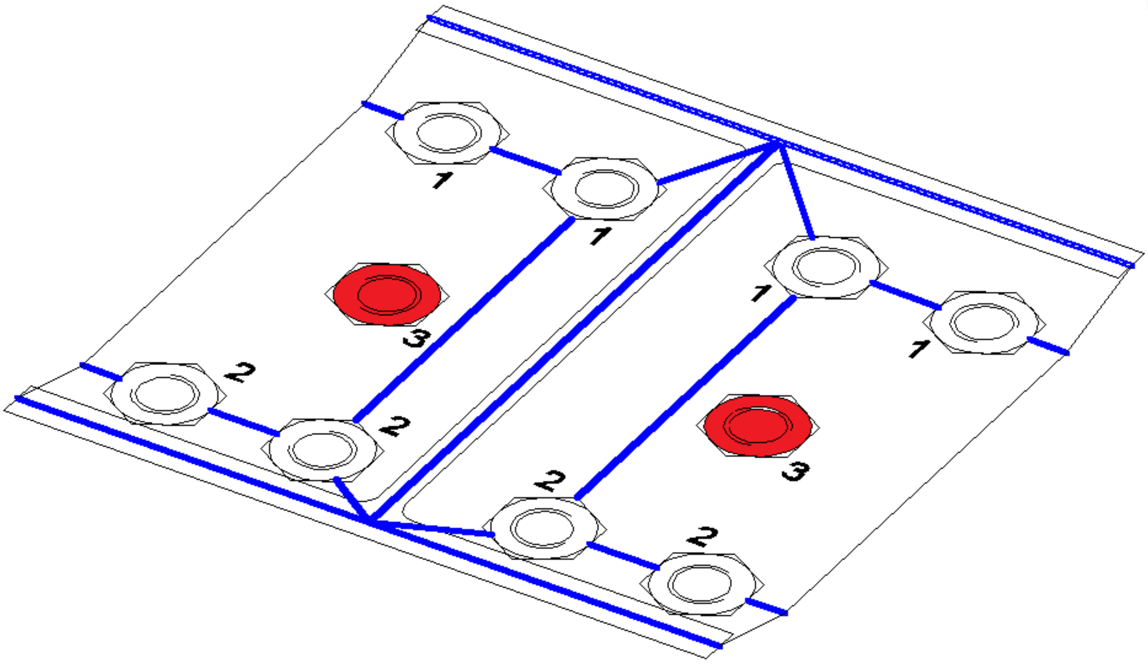

Figure 4*. Drawing of end plate in failed connection. **Blue lines** represent yield lines in end plate. Due to yielding pattern of end plate, bolts near the web of I-beam experience much higher forces. **Nr 3 row center** bolts are **completely useless**, visible on **figure 4** **as red**.*

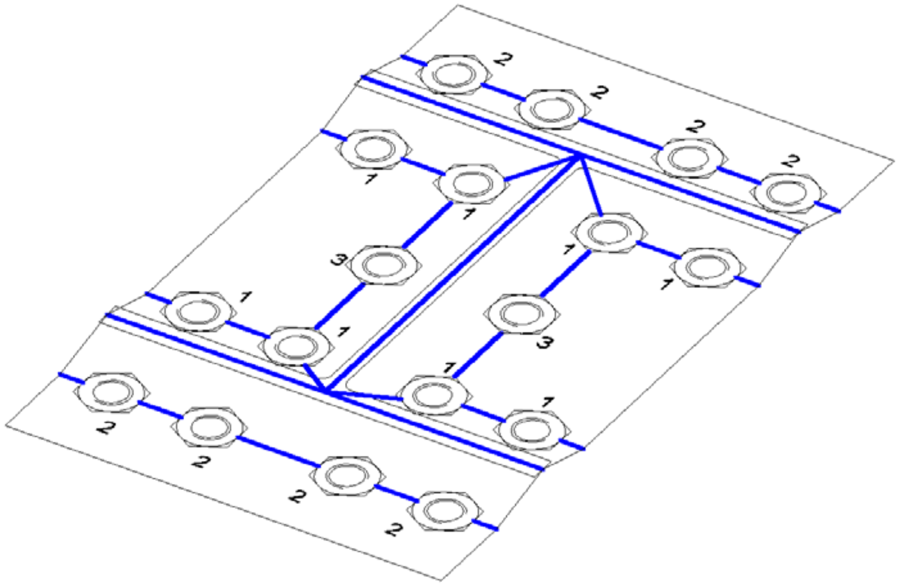

Figure 5.*Excample of properly arranged bolt placement. This connection shows the need of* ***eight additional bolts*** *outside the flanges (in rows nr* ***2****). All bolts are useful in this configuration.* ***Blue lines*** *are representing plate yield lines.*

Figure 6. *Tension connection (****1****) has failed from bolts just as theory would predict. Connection (****2****) has failed during the collapse, since this diagonal is in compression and does not fail or fracture in normal compression loading conditions. Only tension bars and connections rupture.*

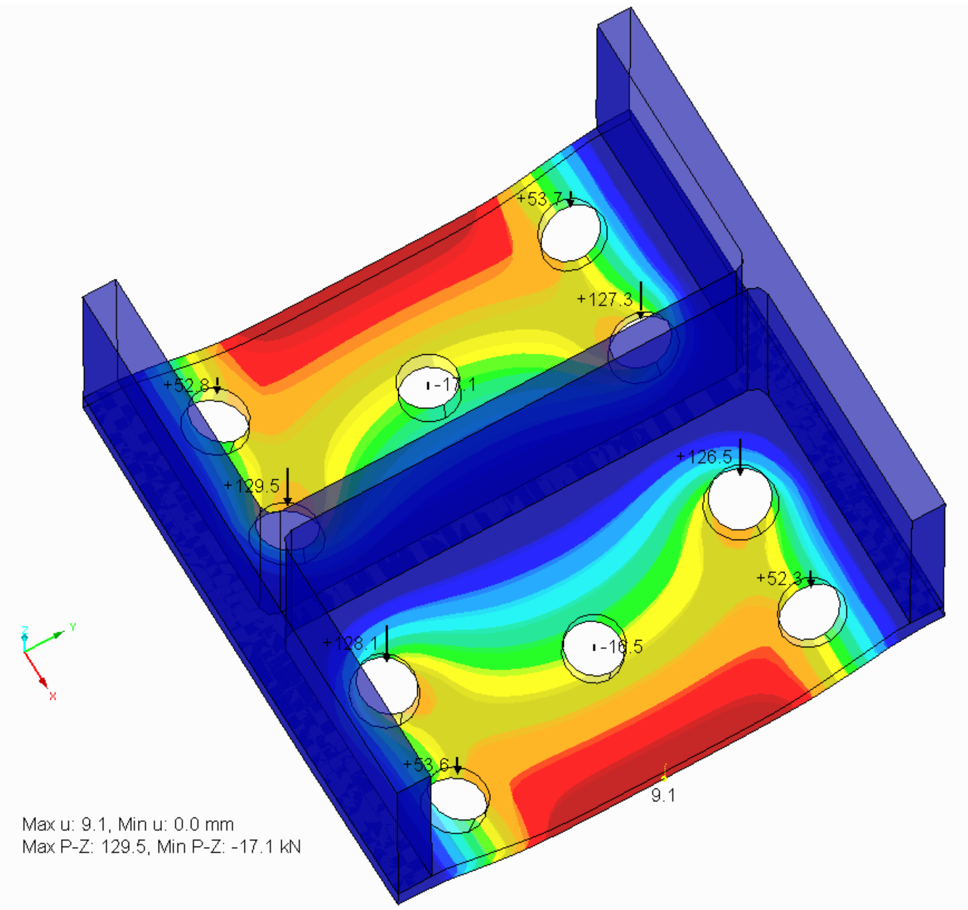

***Figure 7**. Example **FEM** model of the failed connection in Maxima shopping center. Center row **3** bolts are <u>in compression (negative loading in bolts) (totally useless).</u> Bolt forces are not evenly distributed. Maximum loaded bolts will rupture first and then all other will follow. Rupture can cause sound similar to "explosions".*

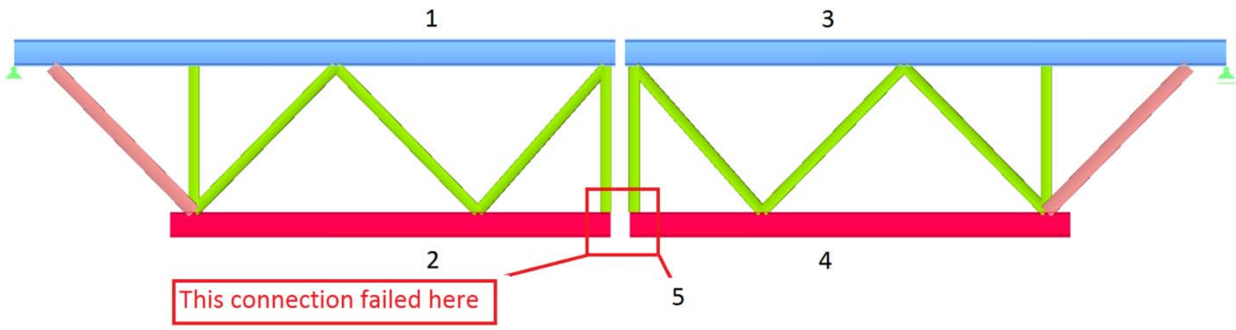

***Figure 8**. Static model of failed truss. Bolted tension -connection in figure **7** is placed in between of massive beams **2** and **4**. Due to fact that this connection was much weaker than beams **2** and **4**, the truss failed in a brittle manner without any prior warning.*

Conclusions:

1. Maxima shopping center collapsed due to under-designed and faulty tension connection
2. Prying forces were not taken into account during design
3. Quantity of bolts is not sufficient for massive I beam section
4. At least eight additional bolts symmetrical to I section massive flanges would have been needed.
5. End plate thickness and dimensions should have been decided based on elaborate yield line method analysis, including all effects of prying force etc.
6. The frame in photos is short. This truss could have been made into single piece, without that dangerous and faulty connection.
7. The failure of this connection can still be tested on site, after the evacuation and rescue work has been completed. This real life test would end all discussions, since high-speed camera can record the process of collapse from many angles and with sufficient high quality. This testing shall be carried out with utmost care and preparation.
8. Video evidence from BBC camera proves all points above. Link is here:
   http://www.bbc.co.uk/news/world-europe-25069941
   Sound of initial rupture of bolts ("explosion like") is clearly audible.
   Building collapsed like a mouse trap.

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