

## Assessment of a Mechanical Failure in a Historic Wood Truss Using Digital Radioscopy

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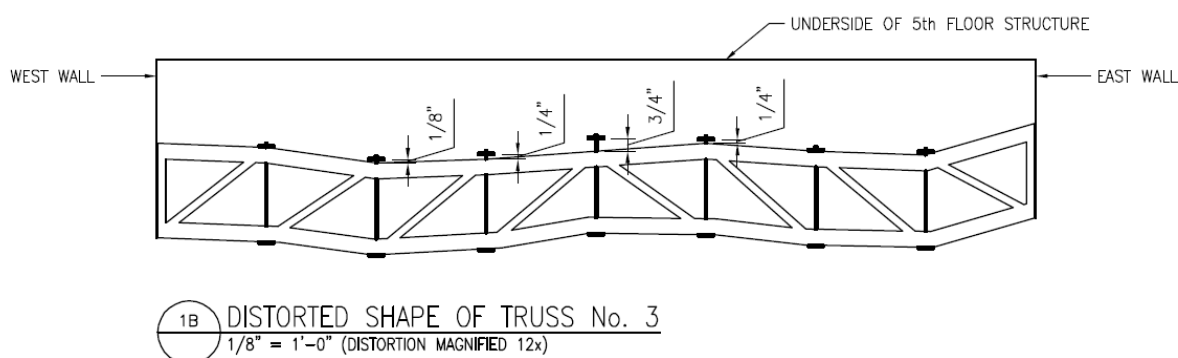
### Background

In 2002, Robert Silman Associates P.C. (RSA) conducted a survey of the structural condition of the south half of the New York State Capitol in Albany, New York, U.S.A. During this survey RSA observed several unusual conditions at the ceiling trusses above the Senate Chamber including visible deflection of one of the trusses and opening of the joints in the decorative trim along the lower truss chord (Figure 1). Following that survey a preliminary structural analysis was conducted and some localized areas of overstress were found; these conditions were noted in 2003 and 2004. In March 2004 a small piece of decorative hardwood trim fell from the ceiling at truss #3.



**Figure 1.** Open joint in the decorative trim of the lower chord of truss #3.

RSA made subsequent visits in 2004 and noted some unusual reverse curvature to the top chord of truss #3 (visible from the attic and shown schematically in Figure 2.). Because the bottom chords of each ceiling truss were covered by the ceiling's historic wood veneer and were hidden from above by insulation, RSA was unable to obtain a complete understanding of the detail and condition of the lower portions of the trusses.



**Figure 2.** Schematic of the deflection of truss #3 in the New York State Senate Chamber.

In 2005 RSA obtained permission to use digital radioscopy on truss #3. Due to its non-invasive operation, digital radioscopy was proposed as a means to examine the truss at key locations identified by the structural engineer to determine the presence or absence

of connections such as steel plates, iron straps, iron bars, or bolts. This information was essential to enable structural modeling. Additionally, a possible failure in the lower chord of truss #3 was to be investigated. The x-ray examination was conducted by Anthony & Associates, Inc. (A&A) in October 2005 in cooperation with Helena Meryman of RSA. Analysis of the failure and design of the repair was done under the guidance of Mr. Robert Silman of RSA. The identification and mechanism of the failure is the focus of this paper.

## **Procedure**

The equipment for the investigation of a potential failure included a pulsed, battery-operated x-ray source that generates approximately the same energy as a dental x-ray but is able to produce images of wood construction over 0.5 meter thick. The imager is an x-ray sensitive screen that is typically mounted on a tripod or placed directly against the surface of the object of interest. The control unit is a portable computer with image processing software which allows for real time display of radiographs in the field. The portable x-ray source was an XR200® x-ray source manufactured by Golden Engineering, Inc. This model is a single packaged, pulsed source, producing x-ray pulses of short duration (60 nanoseconds or  $6 \times 10^{-8}$  seconds each) with minimal dose (3.1 milliroentgens for each pulse at a distance of 0.3 meter from the front of the unit), with energy up to 150 kV. For each image taken, the number of pulses can be set from 1-99. Eight to twenty pulses were typically used to penetrate the ceiling truss.

The digital imaging system used was the EPIX Digital Imaging System manufactured by Logos Imaging. The system is composed of imaging plates, the EPIX scanner and a laptop with software to import and save the scanned images. The imaging plates are reusable, photo-stimulatable phosphor imaging surfaces, 20 cm by 43 cm in size. X-ray images are created on the imaging plates as the phosphor crystals capture the energy of x-rays passing through the object of study.

After exposure, the imaging plate is mounted on a cylindrical carousel and inserted into the scanner. The scanner uses red laser light to cause the crystals to release their stored energy, which is released as blue light captured by the scanner. The scanning process can capture the image at either high or low resolution. The laptop and software associated with the EPIX system capture this image and save the file as a TIF image for post processing.

This imaging system produces digital radiographs that are available for viewing within five minutes. It is easy to shift the imager if needed when the area of concern is not included in the image, or to shift the imager along an object (such as the truss chord) to make sequential radiographs. The images are stored to allow for post-processing to enhance features of interest within the image.

Since the images are TIF files, they can be manipulated by any standard photographic-enhancement software. However, the control unit (the software that is included for the laptop) includes a package that can also be used to enhance the images so that subtle details of the x-ray can be investigated. This software includes not only the standard image-enhancement techniques (such as image sharpening and contrast stretching), but also features designed to assist specifically with x-ray enhancement (such as the ability to transmit all the grey tones of the x-ray into a full spectrum of colors, and edge detection algorithms).

## **Field Investigation**

Scaffolding was erected below the truss in question to allow full access along the length of the lower truss chord (Figure 3). The scaffolding provided a platform for placing the x-ray source in various positions to capture images at successive locations along the lower truss chord (Figure 4). An example of the source position is shown in Figure 5. Note in Figure 5 that the decorative trim has separated due to deflection of the

truss. The source was typically placed 30 to 50 cm from the front face of the decorative wood trim over the truss chord. The truss measured approximately 46 cm from front to back face.



**Figure 3.** Scaffolding positioned below the ceiling truss



**Figure 4.** Scaffolding platform used for radiography setup



**Figure 5.** X-ray source positioned to take an image through the lower truss chord

Images were taken along the truss between two purlins. A typical setup consisted of "pointing" the source towards the area of interest so that the imaging plate could be placed on the opposite face of the truss chord. The placement of the imaging plate was critical for attempting to locate structural rods, fasteners, plates and, if present, any potential fractures in the truss chords. Figure 6 shows the position of the source and the imaging plate for this exposure is oriented as shown in Figure 7.

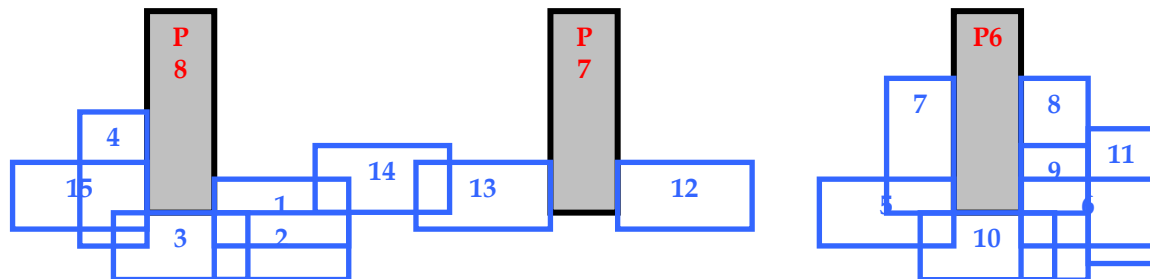


**Figure 6.** X-ray source positioned to take exposure #15



**Figure 7.** Placement of imaging plate for exposure # 15

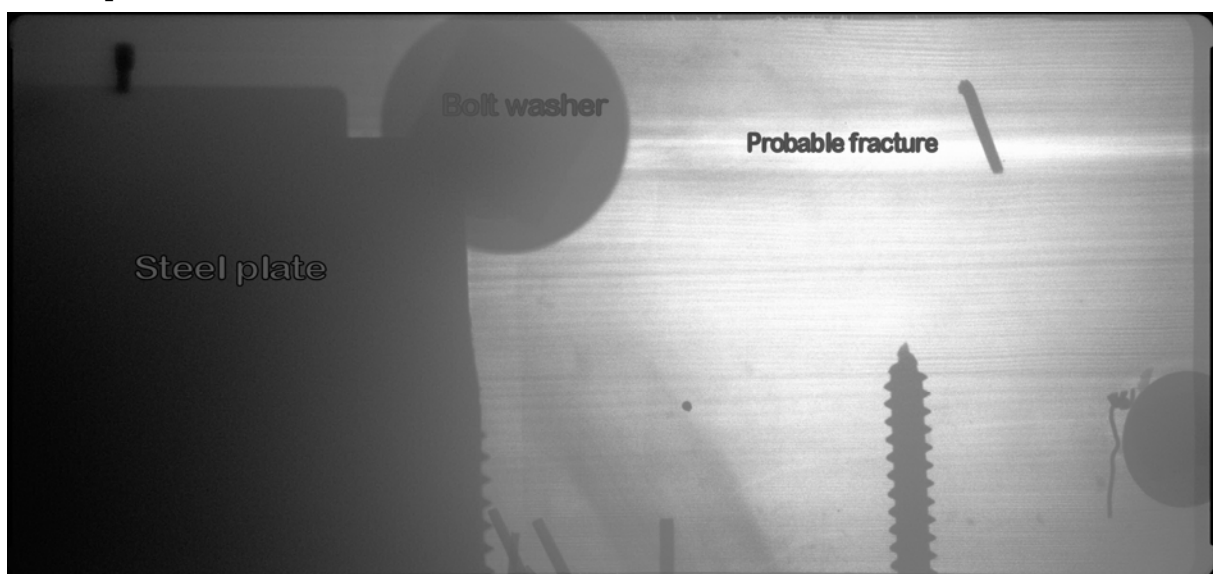
Images were captured systematically along the length of the lower truss chord from purlin 6 to 8, which was the area of interest to the structural engineer. The schematic shown in Figure 8 shows both the location and orientation of the imaging plate for each exposure.



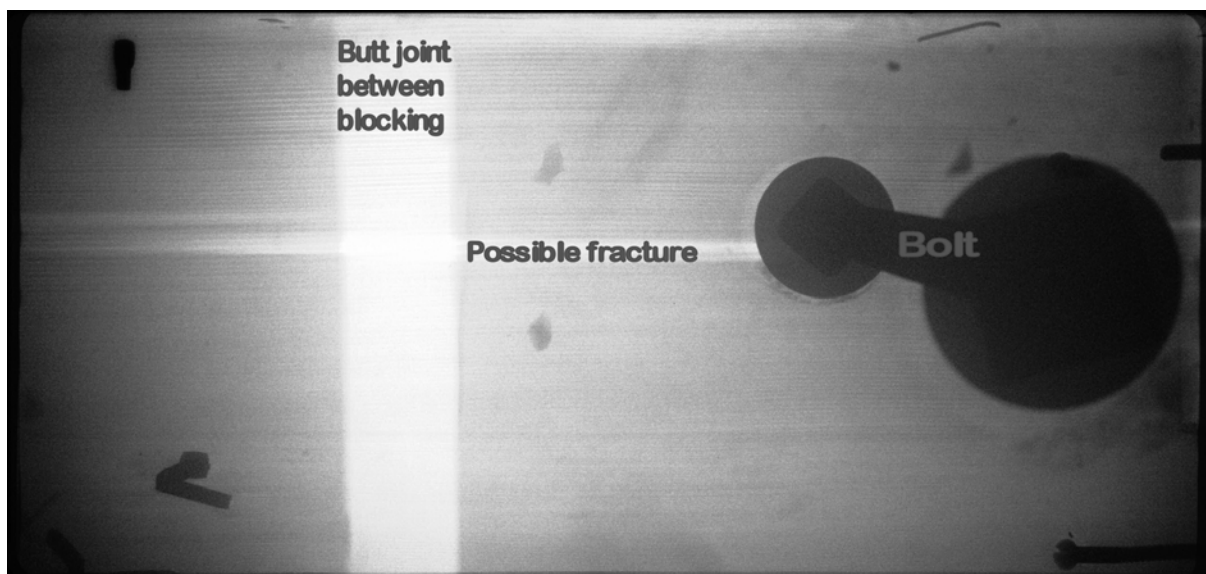
**Figure 8.** Schematic of the position of radioscopic images. Purlins are colored gray and labeled in red (P6 through P8). The imaging plate locations and orientation corresponding to each exposure are in blue.

The radiographs successfully identified metal connections of the truss system, such as screws, nails, threaded rods, bolts and steel plates. In addition, the sensitivity of the radiographs was sufficient to identify more subtle features, such as wood grain in the trusses and decorative carved wooden trim. Key elements were labeled on each radiograph as illustrated in Figures 9 and 10. Each radiograph is oriented to show the internal view of the truss chord as it appears below the imaging plate (as opposed to being viewed from the source side of the truss). The important features observed in all the radiographs can be summarized as follows:

- Steel plates were present below where purlins 6 and 8 intersect the truss.
- Vertical threaded rods were visible at purlins 6 and 8.
- No steel plate was present below purlin 7 at the truss.
- A wood diagonal truss chord was visible at purlin 6.
- A probable fracture (as opposed to a seasoning check in the lumber due to drying) was visible in shots 15, 1, 14, 13 and 12 (proceeding from west to east). The fracture extends from west of purlin 8 to west of purlin 6.
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**Figure 9.** Radiograph of exposure #1



**Figure 10.** Radiograph of exposure #13

At this evidence of a fracture in the bottom chord, RSA requested that the historic veneer be removed to confirm the distress and to expose the entire bottom chord of the truss where additional distress may occur. The veneer was removed under the supervision of the architectural office of Einhorn Yaffe Prescott. On 28 November 2005 RSA was on site to find a total failure in the northern member of the bottom chord (Figures 11 and 12). The location of the failures is west of center, less than a cm west of the last x-ray image taken. The crack documented by the x-rays was an overstressed response of the southern member to the complete failure of its companion.



**Figure 11.** Split bottom chord, east end of failure

The failure discovery warranted immediate action. A repair had to be in place and the scaffolding removed by 31 December 2005 in order to allow for the Senate to open its 2006 session in the chamber. Thus, in less than 35 days repairs had to be completed.

The distress in truss #3 appeared to be related to several factors: the absence of adequate lateral bracing to the top (compression) chord of the truss, the presence of some lateral rotation of the truss, and the introduction of some additional loads from mechanical equipment and lights in the attic above the ceiling. There were no obvious signs of poor construction (such as visible splitting of the wood or substandard condition of connectors).



**Figure 12.** Split bottom chord, west end of failure

The short period of time available for the repair limited the options for repair or replacement. Due to the utter failure of truss #3, reinforcement of the original wood member was not a feasible option. RSA provided schematic designs for a steel companion or sistering trusses to carry the existing timber truss and all of the associated loads. These schematics were reviewed on site by RSA, senior representatives of the State of New York, and three local steel fabricators and erectors to assess constructability in such tight quarters. The design was refined based on field observations and refined again based on the fabricators field measurements. The shop drawing production and review process was expedited resulting in a same day turn around for revisions. The design and fabrication of the structural repairs to truss #3 was a collaborative undertaking that took into account the thoughts and comments of each responsible party.

Repairs to truss #3 included the fabrication of new steel truss that would be installed beneath the top chord and above the bottom chord of the existing wood truss. The new steel elements included new steel 10.2 cm x 10.2 cm x 0.64 cm tube sections for the top chord, new 10.2 cm x 5.1 cm x 0.64 cm vertical tube sections, and new diagonal steel rods with threaded ends and clevises. It was also recommended to the State of New York that inspections and repairs of the other trusses in the Senate Chamber ceiling be conducted. That work is scheduled for 2008.

## Conclusions

A failure in the lumber used in the lower chord of a ceiling truss in the Senate Chamber of the New York State Capitol was identified using digital radioscopy. The potentially life-threatening truss failure was identified, and the repairs were done quickly with minimal disturbance to the rest of the ceiling. This use of digital radioscopy to identify the failure shows the potential for this technology in investigating other potential failures or structural damage without disturbing historic fabric.