A Field Investigation of a Large Collapsed Structure: A Student Engagement Project

Shane M. Palmquist, PhD, PE[1]

Ronald Gallagher, PE, PLS, CPG[2]

Abstract – A large barn structure located in a rural county in Kentucky collapsed during construction on October 14th, 2006. As the crane was moving the last truss into position, the entire roof system suddenly collapsed. The cause of the collapse was not immediately known. Within days of the collapse, students in a junior level structural analysis course got an opportunity to investigate first hand to determine the cause and the sequence of events that lead up to and during the collapse. Based on documented site visits and on statements given by the contractors and the owner, who were present at the time of the collapse, students were required to investigate and write a report to determine the cause and nature of the collapse. The focus of this paper is to present the results and work performed by the students.

Keywords: Collapse, roof trusses, barn structure, structural investigation, and student assessment.

Introduction

Practice based projects should be a part of engineering courses. This approach relates basic engineering concepts taught in the classroom to real life engineering problems faced in practice. It is important for engineering students to understand that the study of engineering by nature is both academic and practice based. In the past several decades, greater emphasis has been place on academic studies [1].

A large private barn structure located in a small rural county in Kentucky collapsed during construction on October 14th, 2006. See Figures 1 and 2. The horse barn was 80 ft wide by 120 ft long in plan and had 80 ft long wooden roof trusses. As the crane moved the last truss into position on the end wall of the barn, the entire roof truss system suddenly collapsed. The surrounding walls remained in place. However, one of the exterior walls bowed outward requiring immediate bracing of the wall to prevent additional outward movement of the wall.

The cause of the collapse was not immediately known. Several potential contributing circumstances existed, which included: possible weather related conditions somewhat unique to south central Kentucky, the condition of the new wooden trusses prior to installation, and the construction practices performed during the erection of the trusses.

The Project

Within days of the collapse, students in a junior level structural analysis course got an opportunity to investigate first hand to determine the cause and sequence of events that lead up to and during the collapse. Based on documented site visits and on statements given by the contractors and the owner, who were present at the time of the collapse, students were required to investigate and write a report to determine the cause of the collapse and nature of the collapse. In addition, as part of the scope of the report, the students were required to give recommendations as to how to prevent such a situation from occurring in the future.

[1] Assist. Prof., Dept. of Engrg., Western Kentucky Univ., Bowling Green, KY 42101, E-mail: shane.palmquist@wku.edu

2 Assist. Prof., Dept. of Engrg., Western Kentucky Univ., Bowling Green, KY 42101, E-mail: ronald.gallagher@wku.edu

Figure 1: The exterior of the collapsed barn looking north

Figure 2: The collapsed trusses looking south

Purpose and Project Phases

The purpose of the project was to give students an opportunity to investigate the collapse of an actual structure. The investigation was extensive, requiring students to careful examine statements given by the contractor and owner who were present at the time of the collapse. In addition, students had to consider local weather conditions on the day of and the days leading up to the collapse, the condition of the new trusses prior to installation, and the construction practices performed during erection of the trusses. Because of the magnitude of the investigation, the project was divided up into several phases. The phases included: a literature of search of similar type collapses, inspection of the collapsed trusses, determination of local weather conditions near the time of the collapse, construction procedures used by the contractor during installation of the trusses, review of the statements given by the parties involved, and determination of proper construction practices for installation of wooden trusses. Each group of students was responsible for inspection of the collapsed structure and one of the other phases. The leaders from each of the groups were then required to write a report, which was then reviewed by each of the members of each of the groups.

Collapsed Barn Structure

The collapse occurred during installation of the last wooden truss at the north end of the barn. The barn faces the north and is 80' by 120' with 80' wood roof trusses spanning in the east to west direction. The structure has two types of trusses. The gable trusses at the north and south ends of the structure are referred to as GE-1 and GE-2, respectively. The interior trusses are referred to as T trusses and are label from north to south from 1 to 23, respectively. The trusses were spaced at 5'-0" on center. The trusses were supported by 16' high walls of wood framing. The walls were supported by masonry block walls. The self weight of the trusses was 821 lbs for the interior trusses (T 1-23) and 969 lbs for the gable trusses (GE 1 and 2). The trusses are designed for a dead load of 14 psf and 20 psf for live load based on the "Minimum Design Loads for Buildings and Other Structures" (ASCE 7-05) [2].

Student Field Work

Students arrived at the collapsed structure to document the collapse. See Figure 3 and 4. The students were divided into groups to assess the damage. Prior to entering the barn, where all of the collapsed trusses had fallen, the groups walked around the structure to view the condition of the exterior walls. The west exterior wall was bowing outward and was temporarily braced. Wearing hardhats, the student groups entered the barn to survey the area of collapsed trusses. No opinions as to the cause of the collapse were given by the faculty. The student groups were left to discuss what happened amongst their group. During this time, the students were required to document by taking notes and photographs of locations of the collapsed trusses and any other documentation they felt pertinent to the investigation. Each of the groups visited the site of the collapse barn twice.

Figure 3: Students discussing collapse scenarios

Figure 4: Students taking notes of collapsed trusses

In addition, students were able to read statements given by the contractor and owner, who were on site at the time of the collapse. From the statements, the students learned that apparently during shipping a large number of stacked trusses all had a broken connection plate at one location. However, these locations were repaired prior to truss installation. Also from the statements, the weather did not appear to be a factor in the collapse, which was confirmed by local weather reports found on the Internet.

Two groups started researching similar type collapses on the Internet and at the Western Kentucky University library. Students read that the most common reason for this type of collapse was a lack of diagonal bracing during the installation of the trusses [3, 4]. The literature indicated the need for contractors to follow the recommendations of the Building Component Safety Information Booklet (BCSI) 2006 [5]. In this document, there is a section titled "Guide to Good Practice for Handling, Installing & Bracing of Metal Plate Connected Wood Trusses." This guide gives detailed information on how to properly brace the top chord, bottom chord, and webs of the trusses during installation. This information was given to the contractor upon delivery of the trusses, and the contractor was required to sign stating that they had received this information.

Knowing the recommendations of the Guide [5], the students went back and read the statements given by the contractor at the time of the collapse. The exterior walls were all properly braced. The south exterior gable truss (GE-1) was externally diagonally braced at four (4) locations. See Figure 1. Only, the first and third quarter points at top chord were braced. The other two braced locations were near the middle of the truss but were braced at the midheight of the truss' web. On the barn's interior, this truss was also braced at top chord at the first and third quarter points of the truss. The interior diagonal bracing at the first and third quarter points also attached to the second and third trusses (T-1 and T-2) at the web and bottom chord, respectively. The remaining trusses (T-3 through T-23) were only braced horizontally along top chords at six (6) locations and along bottom chord at four (4) locations. No other diagonal bracing was provided to the top chords or to the webs of the trusses.

Results of Collapse Investigation

The following are excerpts from the report that the students prepared.

Sequence of Events during the Collapse

The top chord of the third truss (T-2) appears to have buckled and twisted out of the plane of the truss, causing the east half of the truss to twist and fall back to the south onto the east half of the second truss (T-1). See Figures 5 through 7. The impact knocked the second truss (T-1) off its east bearing. The east end of this truss then fell to the ground, causing significant damage near midspan along bottom chord, where the moment is maximized. The remaining west half of the third truss (T-2) twisted and fell to the north toward the fourth truss (T-3). See Figure 8. At which point, the remaining trusses (T-4 through T-23) began to topple on top of each other and collapse in a domino like manner, one on top of the other.

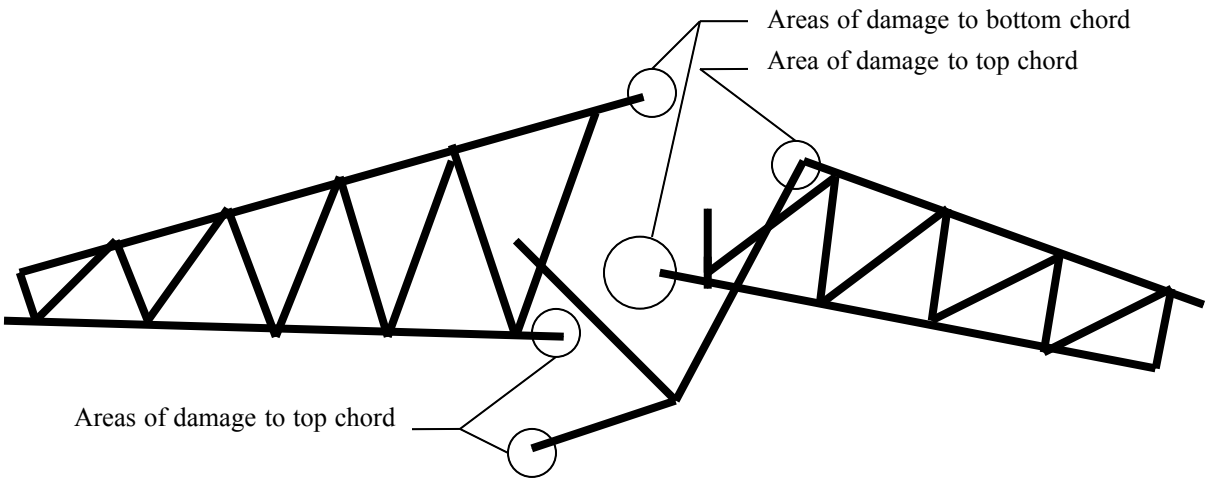

Figure 5: Truss 3 (T01-2) collapsed looking from above

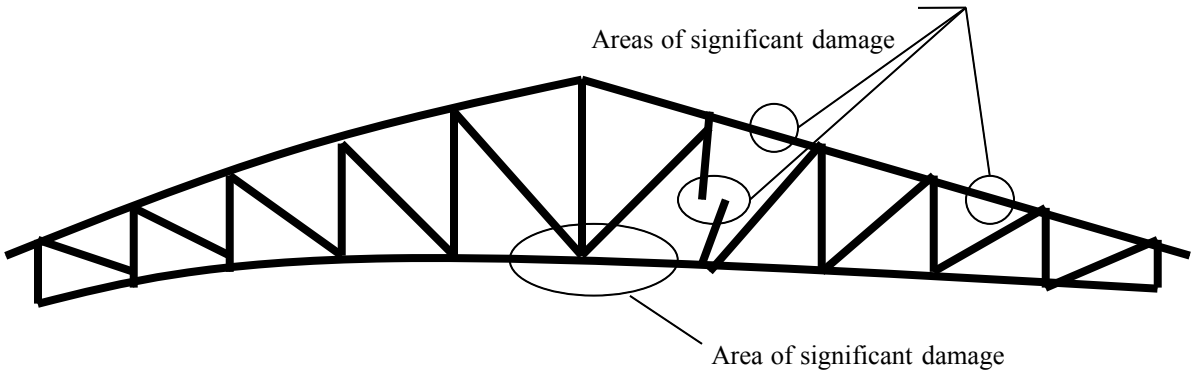

Figure 6: Truss 2 (T01-1) collapsed looking from above

Trusses Provided by the Manufacturer

The design of the trusses for the structure, based on the specifications provided by the truss manufacturer, was satisfactory. The sizes of the plates on the trusses were correct based on the specifications. However, approximately half of the trusses delivered to the site had a broken connection plate, which required repair. Upon further inspection of the collapsed trusses, gaps (not due to the collapse) of up to approximately 1/16" between the plates and the wood members were found at some locations. In addition, some plates did not appear to grip well to the wood members, while most did.

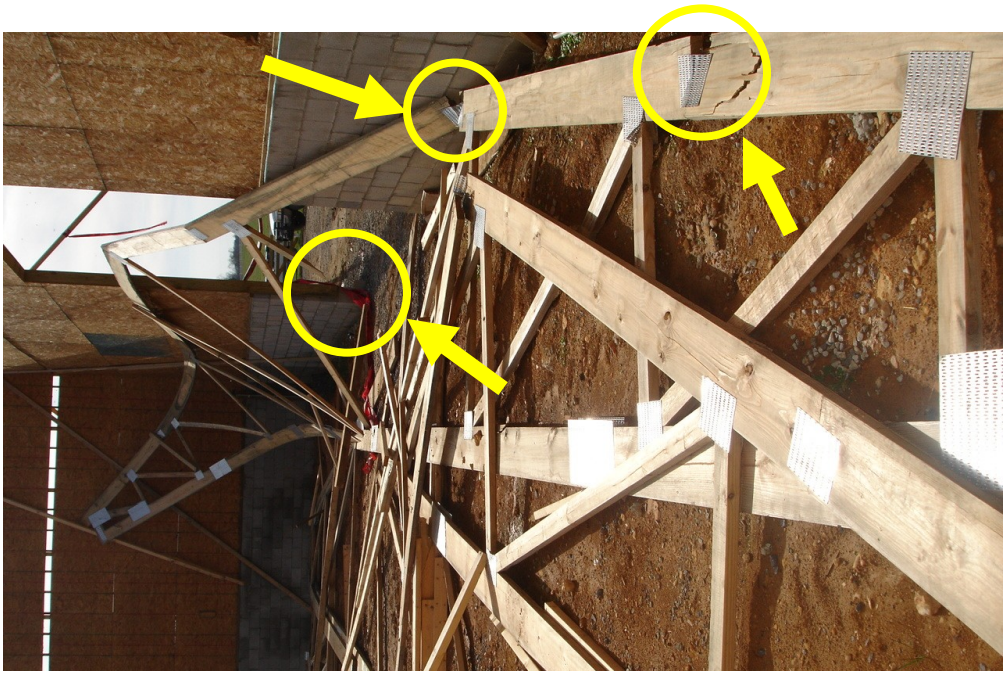

Figure 7. Truss 2 (T01-1): areas of significant damage

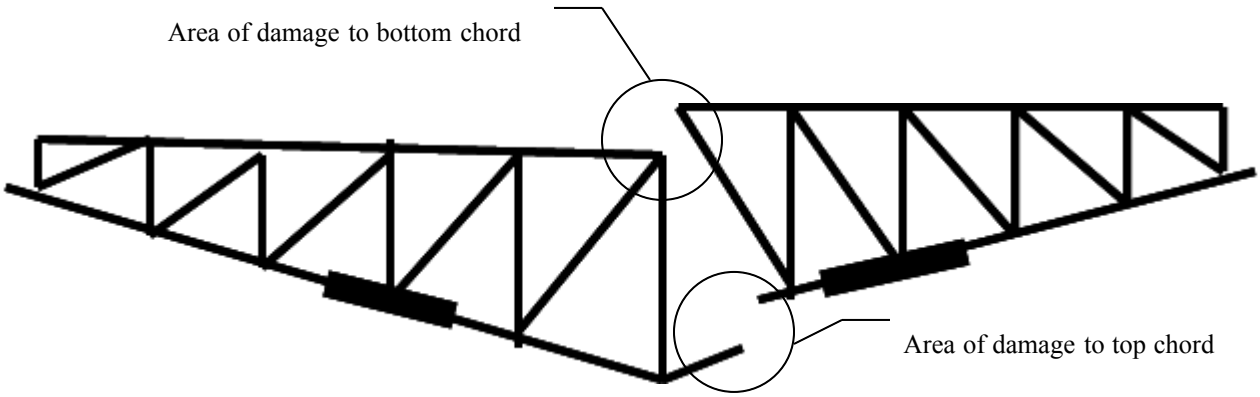

Figure 8: Truss 4 (T01-3) collapsed looking from above

Truss Installation by the Contractor

The top chord and bottom chord of the trusses were laterally braced by horizontal 2x4 boards, which were fasten to each truss as the ends with two or three 16d hand driven sinker nails. The nails were 3¼" long and 0.149" in diameter. Limited bracing as discussed earlier was provided.

However, the bracing was not adequately to prevent the connected trusses from tipping over as a unit, which is what happened when the west half of the third truss (T-2) fell toward the remaining trusses (T-3 through T-23). This would have been prevented by proper diagonal bracing of the trusses. With the exception of the first two trusses (GE01-1 and T01-1), no other trusses were diagonally braced in the web or at top chord. To prevent a tipping failure of the trusses, diagonal bracing of the trusses was required.

Conclusions & Recommendations

In the opinion of the student authors, the collapse was primarily the result of inadequate bracing, specifically the lack of proper bracing of the webs and top chords of the trusses. The condition of the "new" trusses was less than ideal, and this was a contributing factor.

In general, trusses are not marked in any way to identify the frequency or location of temporary bracing, including diagonal bracing. As a result, it is necessary to follow the recommendations as specified in the Building Component Safety Information Booklet (BCSI) (2006) "Guide to Good Practice for Handling, Installing & Bracing of Metal Plate Connected Wood Trusses," Section B10, "Post Frame Truss Installation and Bracing." The guide gives detailed information on how to properly diagonally brace trusses during installation. Proper bracing of the trusses is required.

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Shane M. Palmquist

Shane M. Palmquist is an assistant professor of civil engineering in the Department of Engineering at Western Kentucky University. Prior to becoming a faculty member at WKU, Dr. Palmquist was a structural engineer for Lichtenstein Consulting Engineers in Natick, Massachusetts. He received his BS in civil engineering from the University of New Hampshire, his MS in civil engineering from the University of Rhode Island, and his PhD in civil engineering from Tufts University. His technical interests include project-based engineering education, bridge engineering, construction, and project management.

Ronald Gallagher

Ronald Gallagher is an assistant professor of civil engineering in the Department of Engineering at Western Kentucky University. Prior the joining WKU, he taught at the University of Toledo and has worked at several consulting engineering offices in the Toledo Ohio and Kansas City Missouri areas.