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Lessons Learned from a Forensic Engineering Investigation of a Scaffold Support Failure

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Abstract

During use, a scaffold support allegedly failed, causing injuries to the user when he fell. The plaintiff's expert identified a defective weld as the cause of failure and opined that the product was improperly designed. This paper examines methods used to evaluate the circumstances of and claims made regarding the incident. A combination of engineering methodologies, including metallurgical evaluation, stress analysis, and physical testing, was used to examine the plaintiff's claims of deficiencies in the design and fabrication of the product. The engineering methodologies refute claims made about the structural capacity of the product by the plaintiff's expert and the fundamental cause of failure. This paper examines themes related to the presence of apparent defects/failure and the necessity of verifying postulated hypotheses. It also examines the efficacy of analysis and testing as part of implementation of the "forensic engineering method" in verifying or rejecting hypotheses en route to offering expert opinions in forensic engineering investigations.

Keywords

Product liability, the forensic engineering method, scaffold, failure analysis, finite element analysis, empirical stress analysis, load testing

Introduction

In forensic engineering investigations of product failures, the mere presence of a defect is insufficient to conclusively determine the cause of an incident. Rather, it must be shown by credible and reliable engineering methods that the product is defective, the defect renders the product unreasonably dangerous, and the defect is the primary cause of the incident in which harm is incurred. This paper uses a scaffold collapse incident to examine the necessity of providing engineering analysis, calculation, and/or testing to show the link between the defect and the incident. Furthermore, the ramifications of presenting preliminary findings and opinions formulated prior to litigation are examined. Use of the forensic engineering method as a road map for ensuring the validity of opinions is considered, and the relationship between the forensic engineering method and the legal doctrine of strict liability is investigated.

Background

The incident upon which this case study is based involves the failure of a tripod-style scaffold support. The product features a ladder-style fixed frame with extendable legs. An extendable third leg is attached to the upper cross-member of the frame via a hinged connection. A graphical representation of a scaffold support is shown in **Figure 1**. The scaffold frames are used in pairs to support a scaffold plank. The advantage of the independent scaffold supports with adjustable legs, according to the manufacturer, is that they can be used on uneven ground while maintaining a level and stable working surface.

The tripod leg is attached to the top horizontal member (cross-brace) of the frame via a hinge mechanism, as shown in **Figure 2**. Two aluminum alloy 6061-T6 lugs are welded to the aluminum alloy 6005-T6 extruded member. The top of the tripod leg is secured between the lugs by a cap screw. Each lug is welded to the top cross-brace with a 0.25-inch fillet weld on the outside of the lug.

Incident

The scaffold user in the present case was a homeowner who claimed to have extensive commercial construction experience, including considerable knowledge of scaffolding and its use. He purchased the pair of scaffold supports

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new and claimed to have used them four times prior to the day of the incident — each time without incident. On the day of the incident, he was using the scaffold system at his house to install new siding.

In his deposition, he testified that he set up one of the supports on a concrete pad adjacent to the wall of the house on which he was working. The other support had one leg on the same concrete surface. The user testified that he had cut boards on which the other two legs were placed because they were located on gravel or dirt. On the day of the incident, he claimed that he was using an extendable aluminum plank (scaffold platform). Contrary to his statement that he had used the scaffold supports four times prior to the day of the incident without incident, he also testified that he had used a wooden board on a previous day, but had fallen off the wooden plank, citing instability of the scaffold supports as the reason for the fall.

Figure 1
Graphical representation of tripod scaffold support.

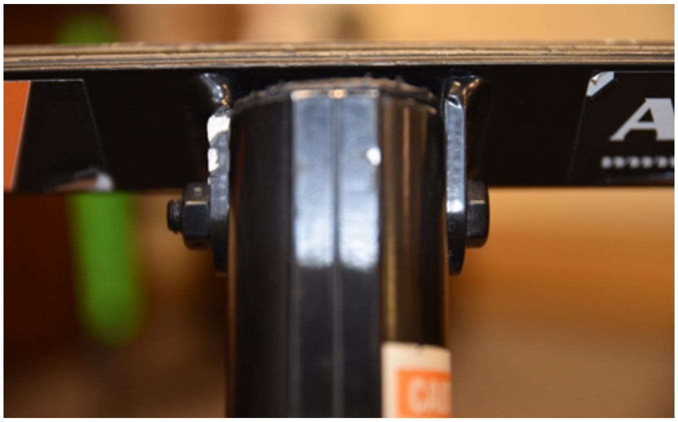

Figure 2
Arrangement of lugs and attachment of top of tripod leg to upper cross-brace.

His testimony varied as to the height of the plank on the day of the incident, but the totality of his statements suggested that the scaffold supports were up with the legs at maximum extension.

The user employed a ladder leaning against the house to ascend to the plank. When he walked to one end of the scaffold, the support at that end failed (he claimed) suddenly and without warning, causing him to fall and strike his head. He testified that after he regained consciousness, he went into the house, and then returned to the location of the scaffolding — whereupon he threw the planking and the support that reportedly had not failed into a neighbor's yard in frustration. He testified that he did not throw the collapsed scaffold support.

Applicable Standards and Load Rating

ANSI/ASSE A10.8, *Safety Requirements for Scaffolding — American National Standard for Construction and Demolition Operations*, is the specification that prescribes certain performance criteria and usage requirements for scaffolding and is applicable to the scaffold that is the subject of this investigation[1]. Furthermore, a warning label attached to the product states that it meets or exceeds the requirements of ANSI A10.8-2001.

Among other performance criteria, ANSI A10.8 states, "Scaffolds shall be capable of supporting, without failure, their own weight and at least four times the maximum intended load." The standard defines failure as: "The condition in which a component or assembly can no longer support the load (also known as load refusal)."

The manufacturer's stated load rating is 300-lbf per support or 600-lbf per pair. The manufacturer also claims that each support weighs 16-lbm, which was confirmed during the investigation. As such, the proof test load specified by ANSI A10.8 would be 1,216-lb per support.

At the time of the incident, the user claimed that his weight (and the weight of the hand tools he carried) were less than 200 lbm.

Plaintiff's Expert Opinions

The attorney for the user retained an engineering expert to examine both the failed and unfailed scaffold supports — and to offer preliminary opinions as to the cause of the failure and the incident. The expert's pre-litigation report letter (on behalf of the plaintiff) claimed that the scaffold support failed because welded lugs at the top of the tripod had separated from the frame, resulting in the collapse of the structure. The report claimed that the failed weld did not bond properly to the aluminum frame, the lack of penetration made the weld the weakest link in the connection, and "relatively little force was required to separate this lug from the frame."

In support of these findings, the plaintiff's expert performed optical microscopy, radiography, and scanning electron microscopy (SEM)* on one or both fractured lugs from the failed support. The radiography and SEM examination (coupled with optical microscopy), it was claimed, confirmed that the weld was defective. Examples are shown in **Figure 3** and **Figure 4**, which contain a photomicrograph of one of the lugs and X-ray of both lug locations.

Figure 3
Photomicrograph from the plaintiff's expert's preliminary report, highlighting lack of root penetration.

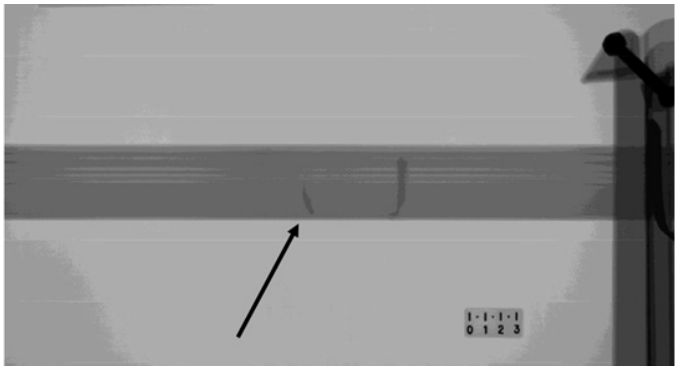

Figure 4
Photograph of radiograph from the plaintiff's preliminary report, indicating "very little weld penetration" on one of two failed lugs.

This expert's pre-litigation report offered the following:

- The scaffold support failed due to inadequate weld penetration of the lug that attaches the top of the tripod leg to the support frame.
- The failure of the scaffold support was due to defective manufacture and not due to improper use.
- The lug, which was welded on one side only, was substantially weaker than subsequent designs in which the lug was welded on both sides; as such, it was inferred, the single weld design detail was inadequate and, thus, related to the failure.

In a subsequent report prepared during litigation, the plaintiff's expert reiterated the preliminary opinions, providing specific focus on weld quality. The second report cataloged a long list of what the plaintiff's expert described as weld defects, and it was further alleged that all scaffold supports welded in the same manner were defective. In neither report did the plaintiff's expert offer any analysis, calculation, or testing to relate the observed weld condition to the failure.

Examination of the physical evidence and review of this expert's documentation showed that the failed weld exhibited (at best) modest penetration at the root of the weld. However, the lugs exhibited evidence of a small amount of ductile deformation or permanent bending. This indicated that the weld was able to withstand sufficient load to allow the lugs to bend prior to fracture, which is inconsistent with the plaintiff's expert's claim that the weld failed at low loads and in a brittle manner. Two views of the failed support are presented in **Figure 5**.

Engineering Analysis and Testing

To evaluate the significance of the observed deformation — and to evaluate the plaintiff's claims that the design of the support was defective because the lugs were welded on one side only — a stress analysis was performed. The analysis consisted of simplified hand calculations, finite

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* The examination required disassembly of the parts to remove the fractured lug from the cap screw joining the lugs and the top of the tripod leg. This was done without notice to other potential parties; as such, representatives for the manufacturer and its experts were precluded from participating in this examination.

Figure 5
Two overall views of failed scaffold support with legs collapsed. Note the fractured lug welds at top of left image and deformation of spreader bar assembly visible in both views.

element analysis (FEA), and empirical stress analysis (testing).

Hand Calculations

Initially, simplified hand calculations were performed to determine the load-bearing capacity of the fillet welds that join the lugs to the frame. These calculations included several simplifying assumptions, including an assumption that the welds were without defect, the welds were oriented vertically (not at an angle with respect to vertical, as they are on the frame), and the weld was loaded only in shear. The allowable stress in the weld was calculated by determining the effective area of the weld as the effective throat multiplied by the length of the weld, as prescribed by AWS D1.2, *Structural Welding Code – Aluminum*. This code defines the effective throat as the minimum distance between the root of the weld and the face of the weld, which would be the leg length multiplied by 0.707 (the cosine of 45°) for an ideal symmetrical fillet weld[2].

Aluminum alloy 4043 is commonly used as a weld filler wire for 6000-series aluminum alloys and is the filler wire specified by the scaffold manufacturer. Product information for 4043 weld wire gives typical as-welded strength values of approximately 18 ksi for yield strength and an approximate tensile strength in the range of 27 to 33 ksi. Using the typical yield strength value of 18 ksi as an allowable stress before safety factors, the allowable load on each lug weld was calculated to be approximately 5400 lbf — or 18 times the rated load for the entire support[+].

Finite Element Analysis

Finite element analysis (FEA) was then employed to further interrogate the adequacy of the structure and the role of the claimed weld defect in the failure. For the purposes of the analysis, a conservative failure criterion was considered to be any stress in excess of the yield strength of the component. The ANSI A10.8 standard defines failure as the inability to support load, which is possible even after materials yield. Thus, the ANSI standard offers a more lenient approach to material failure than the more conservative criterion employed in the present analysis.

Autodesk Fusion 360 was used for the FEA, which was performed using linear elastic methods. Linear elastic analysis is limited to stresses in members up to their proportional limit (the stress at which permanent deformation sets in, similar to the yield strength of the material), while non-linear analysis utilizes full range stress-strain curves for each material to accommodate post-yield plastic (permanent) deformation. However, for the purposes of the present analysis, linear analysis was sufficient to evaluate the adequacy of the design; stresses beyond the yield strength of any component material would not be consistent with the criterion stated above.

A basic model for the FEA is shown in **Figure 6**. The front two feet are constrained against translation and rotation (as they would be on a flat, level surface with

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[+] Although simplified in approach by considering only shear loading, even if combined loading were considered (i.e., shear and tension or transverse tension), it is unlikely that the effects of combined loading would be sufficient to reduce the joint strength enough to exceed the significant safety factor in pure shear.

adequate friction.) The tripod leg foot (rear) is constrained to preclude moving or deflecting in the direction normal to the surface (vertically). The leg is free to rotate, move, or deform in the direction tangential to the surface. In addition, the pinned joints are free to rotate. The rubber feet were omitted from the analytical model, as they do not perform a structural role and the constraints applied to the analysis fulfill the same function as the rubber feet in preventing the legs from sliding on the surface.

The load is applied as a distributed load on the scaffold top brace, as would be encountered in service with the use of a scaffold plank. For this analysis, the load was distributed over a 15-inch distance to match the width of the plank described by the user in his deposition. For the basic analysis, the load was applied in only the downward vertical direction (parallel to the gravity vector) in the same manner as the loading test prescribed in the ANSI standard.

A linear analysis was performed to verify the load rating (300 lbf) of the scaffold support. The loading for this load case consisted of a purely vertical 300-lbf uniform load distributed over the central 15-inch length of the scaffold top brace, as shown in **Figure 7**. This is consistent with the manner of loading that would be expected if the scaffold were used in the manner described by the manufacturer in its instructions and product information.

Figure 6
Overall view of basic model used for finite element analysis.

Results of this analysis showed that the scaffold easily bore the rated load applied in the manner shown in **Figure 7**, with Factors of Safety (against the yield strength of the materials) in excess of 4.8 and maximum (Von Mises) stress of 6.95 ksi. The maximum stress occurred in the tripod leg near hinge pin hole. The maximum stress in the scaffold frame was approximately 4 ksi and occurred in the scaffold top brace adjacent to (but not in) the weld. Results of the analysis are shown in various views in **Figure 8**.

The analysis was repeated using the same model, but with an applied load of 1200 lbf, which is approximately the load specified as the proof load in ANSI A10.8-2001. The same constraints were used as in the previous analysis. Results of this analysis, which are presented graphically in **Figure 9**, showed that the peak stress occurred in the tripod leg near the hinge hole. The maximum stress in the scaffold frame structure occurred in the top brace adjacent to the weld at a magnitude of between 15 and 18 ksi, which is less than half the minimum expected yield strength for the aluminum alloy 6005-T6 member.

Based on the foregoing analyses, the design of the structure appeared to be adequate for the rated load of 300 lbf and the specified proof test load of approximately 1200 lbf, with peak stresses less than half of the yield strength at the higher load. Thus, the safety factor as determined by FEA was more than 2:1 against yielding at the proof test

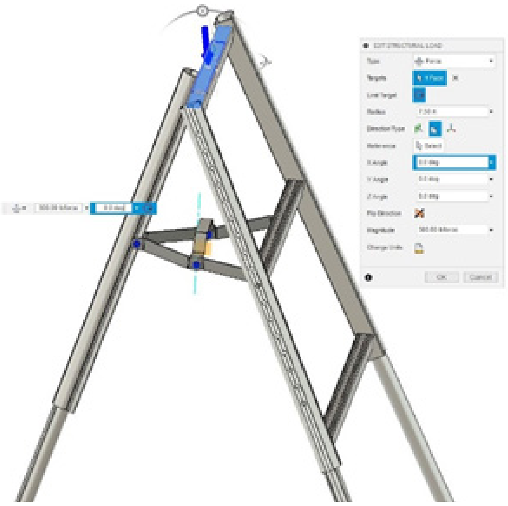

Figure 7
Applied load for 300-lbf rated load analysis.

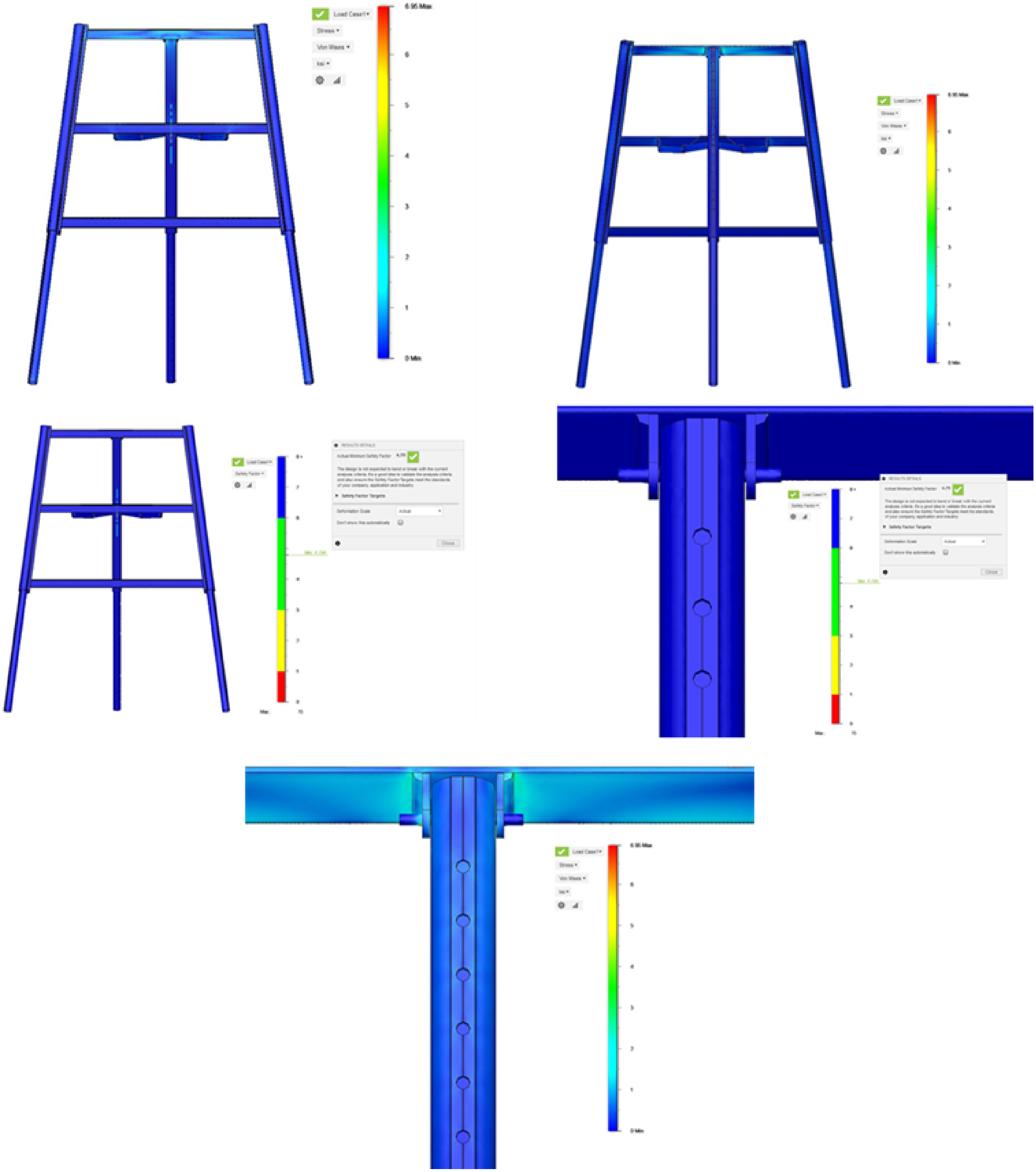

Figure 8
Graphical representations of results of FEA of rated load analysis (300 lbf). Upper left shows front view Von Mises stress (ksi). Upper right shows rear view Von Mises stress (ksi). Middle left view shows front view factor of safety (against yield). Middle right view shows factor of safety in area of top brace lug welds. Bottom view shows Von Mises stress (ksi) in area of top brace welds.

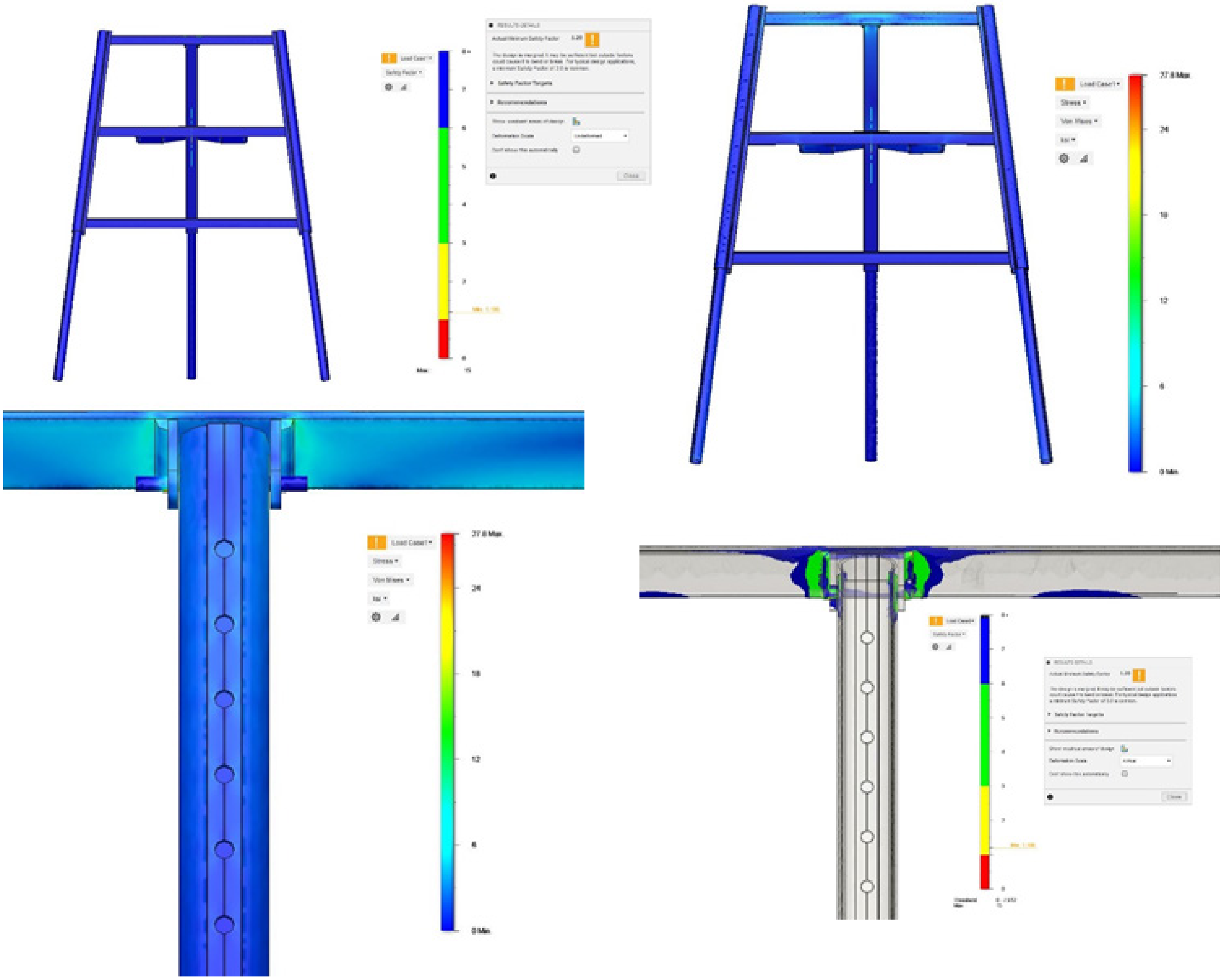

Figure 9
Graphical representations of results of 1200 lbf proof load FEA. Upper left: front view factor of safety. Upper right: front view Von Mises stress (ksi). Lower right: Close-up of Von Mises stress (ksi) in weld area. Lower right: close-up of weld area showing factor of safety.

load, and more than 8:1 against yielding at the rated load. The FEA also revealed that peak stresses did not appear in the lug welds.

The 300-lbf rated load study was repeated, but with the model modified to remove the bond between the lug-to-top brace weld on one side of the hinge (effectively removing the weld from the structure). This case, shown schematically in **Figure 10**, is the worst-case scenario of the plaintiff expert's theory of a defective weld — one that is so compromised as to bear no load at all. This condition represents complete lack of fusion/lack of penetration so that the weld is completely detached from the frame. The analysis was performed with the same loading and constraints as in the first rated load case. Results of this analysis showed that the maximum stress in the scaffold

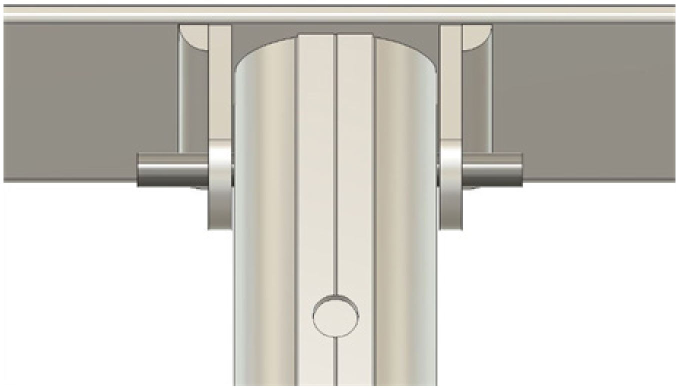

Figure 10
Close-up of lug-to-top brace weld area showing details of model for analyses with one weld detached from top brace. This condition represents complete lack of fusion/lack of penetration of the left-hand weld.

frame occurred in the tripod leg around the hinge hole at a magnitude of approximately 15.2 ksi. The highest stress in the weld area was approximately 4 to 5 ksi in the weld that remained fully bonded. This represented a safety factor between 3.6 and 4.5 against yielding at the rated load — even with one lug weld completely detached.

Load Testing

Two exemplar scaffold supports exhibiting the same weld configuration as the subject evidence were procured as part of the investigation The exemplars were in like-new condition, represented by the seller to have never been used. Examination confirmed that there was no evidence of prior use.

Load tests were performed on exemplar scaffold supports. The scaffold support was set up on cinder blocks, which were resting on a smooth concrete floor. Legs were extended to full length for testing. A piece of aluminum extrusion stock was used to distribute the applied load over a 15-inch length of the top scaffold brace. An electric winch with wire rope was used to apply a tensile load, which was measured using a 2500-lbf capacity load cell. The force value from the load cell was displayed on an indicator paired with the load cell. Smaller ($^1/_8$-inch) diameter wire rope was used to suspend a spreader bar from the loading bar, to which the primary loading line was attached. A representative photograph of the test set-up is shown in **Figure 11**.

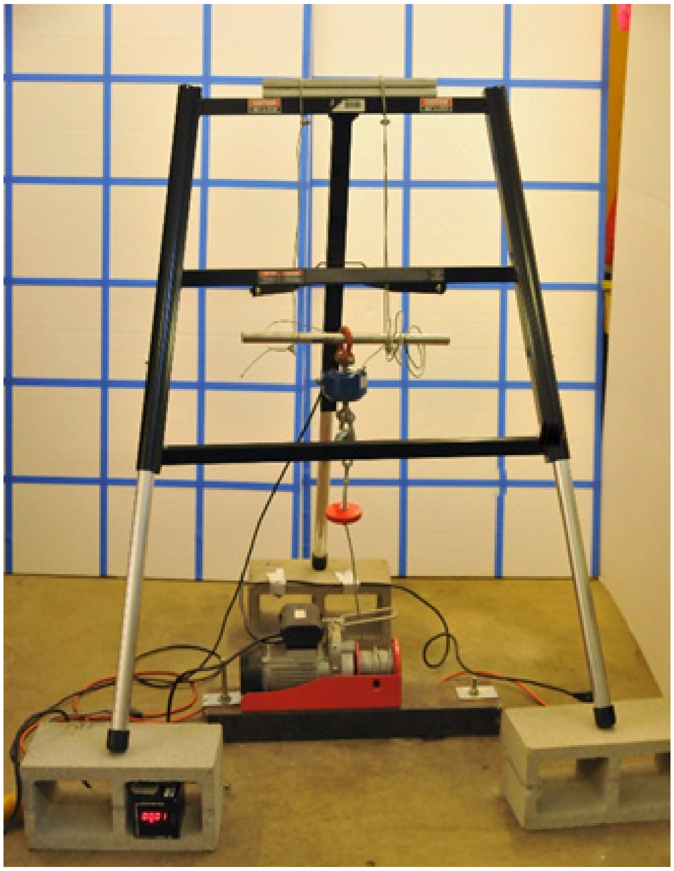

Figure 11
Load test set-up. Load is applied through wire rope (with load cell) to spreader bar, then to loading bar strapped to top scaffold brace.

During testing, it was observed that the application of the load produced a short-duration peak load that diminished quickly to the nominal starting static load. This peak load was detected by the load cell and indicator — and was recorded with the test record. Once the peak load reduced to the nominal static load, it was observed that the static load reduced during the load hold duration (typically four to five minutes) due to relaxation of the structure. Thus, the nominal static load was reported herein as a range (initial load to final load at the end of the load duration).

Several tests were run on an exemplar scaffold. In the first test, the scaffold support design was tested by applying a load in excess of the rated load of the scaffold. A peak load of 414 lbf was observed at the outset of the sustained loading as the load was applied. A sustained load ranging from 330 to 360 lbf was applied to the test article over a period of approximately 4 minutes. No permanent deformation, damage, or compromise in operation was observed to the scaffold support after the load was released.

In a second test, a load in excess of the proof test load specified in ANSI A10.8-2001 (four times the rated load plus the weight of the scaffold, or 1216 lbf) was applied in the same manner as the previous test. A peak load of 2387 lbf was measured before the sustained load settled in at about 1791 lbf, decreasing to 1250 lbf over a 5 minute period. The test article was loaded and unloaded several times prior to establishing the sustained load magnitude. After the test, there was no observable permanent deformation, damage, or compromise in operation.

Following the second load test, one of the upper hinge brackets (lug) was removed from the top scaffold brace by cutting the weld attaching the lug to the brace. This was equivalent to the FEA analysis performed with one weld not bonded to the frame. The load was applied in a manner similar to the previous tests using the same configuration. A peak load of 1098 lbf was measured before the sustained load of approximately 700 lbf was applied over a duration of approximately 5 minutes. As before, there were several load/unload cycles before the load was established at the sustained load magnitude. After the load was released, there was no visible evidence of deformation, damage (other than the removed weld), or compromise in operation of the scaffold.

Two additional tests were run on the exemplar with the removed lug weld. In these tests, the loading bar was moved to each end of the top scaffold brace. Otherwise, the configuration and loading manner were essentially the same as the previous tests (except that the slight misalignment of the loading cable was adjusted to further minimize lateral loading).

With the loading bar to the right (the same side of the scaffold with the removed lug weld), a peak load of 1683 lbf was measured, with a sustained load of 1526 to 1475 lbf applied over a 5-minute period. After the sustained load period, the load was cycled six times before unloading to impart dynamic loading to the scaffold. During loading under these conditions, the scaffold exhibited a tendency to deform by rotating counter-clockwise when viewed from above (or, stated a different way, the end of the top scaffold brace with the loading bar tended to rotate toward the tripod leg). After this test, there was no visible evidence of deformation, damage (other than the removed weld), or compromise in operation of the scaffold.

With the load applied to the left end of the scaffold top brace, the peak load was 1399 lbf, with a sustained load of 1244 to 1117 lbf applied over a 5-minute duration. Following the sustained load, four load/unload cycles were applied, with the highest applied load measured at 2209 lbf. The intention was to load the scaffold to failure; the test set-up was unable to generate sufficient sustained load to bring the test article to failure. Under this offset load configuration, the scaffold tended to translate to the opposite direction, with significant bending observed in the left leg. The left end of the top brace dipped slightly. At the highest load of 2209 lbf, significant bending of the left leg was observed, along with a general translation of the upper part of the scaffold support translating to the right (approximately 3.75 inches at the highest load). As with the first offset load test, no permanent deformation or damage was observed in the test article when the load was removed.

Discussion

The analysis and testing presented above demonstrates that the design of the scaffold support was sufficient for the rated load of 300 lbf per support and the proof test load of 1200 lbf required by the ANSI standard. Maximum stresses predicted by the finite element analyses were significantly below the yield strength of the component materials, and the analyses did not predict failure at the lug welds (nor do the analyses identify the lug welds as the locations of highest stress). With one lug weld absent, FEA did not predict failure at the rated load. The empirical testing also demonstrated the adequacy of the design. Even with one weld completely removed — and with a combination of static and dynamic forces applied — the scaffold sustained a load of more than twice the rated load without deformation, damage, instability, or a compromise in operation of the scaffold.

In the present case study, the fact that test loads of more than 2000 lbf were applied without failure not only showed that the design was sufficient for the rated load, but that extreme circumstances also seemed to be required to cause failure — even when the weld in question played no part in the load-bearing capacity of the structure. Thus, although weld defects like the incomplete root penetration observed in the lug weld were undesirable, their presence may be more aesthetic than detrimental to the structural integrity of the article.

Ostensibly, in the plaintiff's expert's theory (although not specifically elucidated), the collapse of the scaffold and the related deformation of the locking spreader bar components were the result of the collapse of the scaffold after the supposedly defective weld "suddenly and without warning" failed. However, analysis — both theoretical (FEA) and empirical (testing) — were not consistent with the claims. Only under extreme circumstances was catastrophic failure of the weld and collapse of the entire structure likely — even more extreme than completely removing one weld.

The asymmetric load tests (loaded to edge of upper cross-brace) may provide some indication of the potential cause of failure. Although loading to approximately 2000 lbf did not cause failure, examination of the tendency of deformation under this loading revealed that the support began to deform (not permanently) in a manner similar to the deformation observed in the failed support. This suggested that the failure may have been caused by an extreme asymmetric loading condition, one that included a large lateral component (to the side of the support) as well as a large vertical load.

A significant lateral load component could be caused by instability of one or more feet and legs. Recall that the plaintiff had testified in his deposition that he had fallen from the scaffold on a previous day because of instability, which he attributed to the support. After that, he had cut boards to place on the rock or gravel earth surface, upon which he placed the two feet (and legs) of the support not located on the concrete pad. Instability of one of the frame legs and/or the tripod leg would cause lateral displacement of the legs, resulting in deformation of the spreader bar assembly to the side and rotation of the tripod leg, as observed on the subject evidence. Thus, the theory that failure was due to the plaintiff's use of the product cannot be excluded. This is further compounded by the fact that he acknowledged prior instability, causing him to fall. The physical evidence did not allow a conclusive determination as to whether or not this prior incident caused damage to the support; however, it must be considered when arriving at conclusions as to the cause of the incident.

In his deposition, the plaintiff also acknowledged (perhaps unknowingly) other aspects of improper use of the supports and inconsistencies. For example, the user claimed to have used the supports only four times (days) prior to the incident, including one or two days immediately before the day on which the scaffold support failed. Examination of both the failed and unfailed supports showed characteristics not consistent with four days of use, including significant wear on the rubber feet.

The wear was also consistent with expectation if the feet slid on a hard surface. He also claimed to have stored the supports in a garage, out of the elements. However, steel components of the spreader bar assembly exhibited notable corrosion, which was not consistent with his testimony. His testimony also showed that despite his claim that he was an experienced user of scaffolding from his career as a contractor, he failed to comply with the manufacturer's instructions for use and with aspects of usage prescribed by the ANSI standard.

Both the plaintiff's expert and defendant's experts agreed that at least one of the lug welds exhibited evidence of incomplete root penetration. Root penetration is generally considered necessary for fillet welds, such as those attaching the lugs to the upper cross-brace, to meet criteria for quality welds in welding codes such as AWS D1.2. However, there is a difference between complying with welding codes and standards and conclusively determining the cause of failure. The mere presence of an indication of defect in a weld does not necessarily constitute the cause of failure, even if the indication would render the weld rejectable by certain codes, specifications, or standards. The role of the indication or defect in the chain of proximate cause of a failure must be interrogated and proven.

The foregoing information calls into question the competency of expert opinions that are offered without adequate support. The plaintiff's expert disclosure, which included two different reports, conveyed no basis for the link between the observed weld quality and the failure. There were no calculations, analysis, or testing in support of the theory; rather, the expert claimed ipse dixit that there was a weld defect and, ergo, it must have been the cause of failure, without further investigation or interrogation. The disclosure was also critical of the weld detail, claiming that the lug with the single weld was notably weaker than a subsequently manufactured exemplar that featured a lug welded on both sides. The implicit argument, propounded by the plaintiff's counsel, was that the single weld design was inadequate. This assertion was unfounded and irrelevant. Without engineering analysis or testing, the design claim failed to be credible. The fact that a part of the structure can be made stronger is irrelevant, especially when, as defense expert's analysis and testing prove, it is more than sufficient in the first place.

In their paper "Forensic Engineering and the Scientific Method,"[3] authors Liptai and Cecil provide a comprehensive comparison of the Scientific Method, the Forensic Engineering Method, and the similarities and differences between them. Science, they state, "can be defined most succinctly as a department of systemized knowledge," while engineering is "the application of science." The Scientific Method entails observation, formulation of a hypothesis, testing of the hypothesis, data analysis, and confirmation or rejection of the hypothesis in what is often an iterative process. As forensic engineering, which is most often based on the application of existing scientific principles, rarely involves formulation of true hypotheses, Liptai and Cecil outline a modification of that method appropriate for forensic engineering investigations, as shown in **Figure 12**.

This methodology involves observation (of the precedent event or, as in this case, failure), definition of the engineering problem, data collection and analysis, and the development and evaluation of findings. This, like the Scientific Method, is an iterative method. Like the necessity to validate or reject the hypothesis in the Scientific Method, the Forensic Method demands that the practitioner evaluate the findings that emerge from the investigation in the same manner that primary researchers utilizing the Scientific Method fairly gauge the validity of their own hypotheses. To do so, write Liptai and Cecil, the practitioner must engage in some manner of reasonable and credible data collection, which may consist of observation, research,

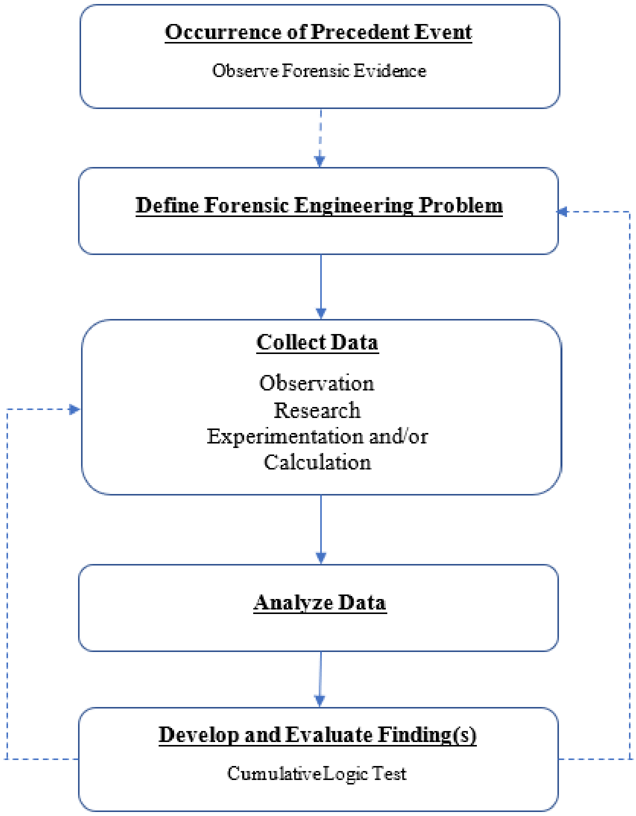

Figure 12
Schematic representation of forensic engineering method (after Liptai and Cecil).

experimentation and/or calculation, followed by reliable analysis of the data. To forward findings, opinions, and/or conclusions without benefit of these two critical steps may yield results that are flawed. More importantly, as with Daubert and Frye challenges, the results may be deemed unreliable because the methodology is flawed.

In the present case, the plaintiff's expert failed to properly collect and analyze relevant data. The plaintiff's expert's second report included a dissertation on aspects of welding practice, but stopped short of tying the perceived deficiencies to the actual failure. Furthermore, relevant evidence (plaintiff's manner of use of the product) was either ignored or was not recognized as a relevant and necessary component of the Forensic Engineering Method.

This concept is also captured by the legal doctrine of strict liability for products. This doctrine places liability on a manufacturer of a product if, as described by Thorpe and Middendorf in "What Every Engineer Should Know About Product Liability,"[4] the plaintiff can prove "that the product is defective, unreasonably dangerous, and the proximate cause of the harm." This is a three-step process. To prevail, the plaintiff must show: 1) that the product is defective; 2) that the defect renders the product unreasonably dangerous; and 3) that the defect is the primary cause of the incident in which the plaintiff suffers some injury or damage. The parallel to the forensic engineering method becomes clear: The forensic engineering method requires the practitioner to directly link the observations and data (i.e., the defect) to the outcome through proper analysis, while the legal doctrine of strict liability requires that the defect be the primary cause of the damage. Thus, good engineering practice and legal theory, although distinct and separate, coincide on the need prove that a specific condition actually caused a specific outcome.

In his pre-litigation report, the plaintiff's expert offered a number of factors associated with the failure, including that the weld defect was the cause of failure, the design of the support was inadequate, an improper filler wire was used for welding, and failure was not due to improper use. It is not unusual for attorneys to retain forensic engineering experts to help them evaluate the merits of a case prior to filing of suit. However, it is imperative that forensic engineers approach their pre-litigation reports in the same manner as those prepared as predicates for expert disclosures within litigation, understanding that the pre-litigation works may become admissible and part of their body of work in the case. Thus, even with the inclusion of conventional boiler-plate language reserving the expert's right to modify or amend opinions later, offering pre-litigation opinions without benefit of the forensic engineering method may be fraught with peril. Potential opinions or conclusions may be better posited in other terms, such as areas for additional investigation. Better yet, such potential opinions might be best reserved until proper data collection and analysis can be executed, even when such activities entail providing notice to other parties. In short, preliminary opinions, even when couched as such, may live on to become issues as the case progresses to and through the litigation process.

Conclusions

The included case study highlights the necessity to complete the chain of proximate cause in forensic engineering investigations. The mere presence of a defect is insufficient to prove that the incident or failure was caused by the defect; rather, there must credible and reliable analysis, calculation, or testing to show that the incident or failure is the direct result of the condition. The Forensic Engineering Method provides a meaningful and accepted route to formulating and affirming reliable opinions.

Furthermore, the case study illustrates the potential adverse consequences of speculative findings and opinions formulated without benefit of analysis, calculation, or testing conveyed in a pre-litigation report. Experts should expect those findings and opinions to become part of their body of work in the matter once litigation is ensued and should treat pre-litigation findings and opinions with the same weight and care as those generated once suit has been filed. In the case study presented herein, a combination of engineering analysis and testing showed claims that the design of the scaffold support was improper were unfounded and cast significant doubt that the weld defect was the primary cause of the failure.

References

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