Investigation of the January 10, 2020, Scaffold Collapse in Saipan, Commonwealth of the Northern Mariana Islands

U.S. Department of Labor
Occupational Safety and Health Administration
Directorate of Construction

July 2020

Report

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Directorate of Construction

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Honolulu Area Office

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1. Introduction

On January 10, 2020, three employees were working on a scaffold attached on the fourth floor of a hotel on Saipan Island, Commonwealth of the Northern Mariana Islands (CNMI), when the cables supporting the scaffold suddenly failed and the scaffold collapsed. The scaffold, approximately 17 feet long and 15 feet wide, was attached to the building and was being used to transfer materials into the building. At the time of the collapse, the employees were moving materials from the scaffold into the building. The employees and materials fell 10 feet to the concrete floor below resulting in three employees being injured. The scaffold was in an unstable condition and remained unsafe after the incident.

Upon receiving a referral, a Honolulu Area Office compliance officer inspected the worksite to examine the collapsed scaffold and determine the contributing causes of this incident. Subsequently, the OSHA Region IX Administrator in San Francisco, California, requested the Directorate of Construction (DOC), from the national office in Washington, D.C., to provide engineering assistance in the investigation of the incident. DOC assisted the Honolulu Area Office in this investigation remotely. DOC staff did not visit the incident site. The safety compliance officer from the Honolulu Area Office visited the site, took photographs of the failed scaffold, took measurements of equipment involved in the incident, and collected the pieces of failed cables from the site for further examination. To ensure the preservation of evidence, the contractor moved the failed scaffold and components to a nearby area and secured them.

2. Description of the Project and Incident

The collapse occurred at the Imperial Pacific International Hotel, CPL Derence Jack Road, Orchid Street Garapan, Saipan Island, MP, 96950. The project involved expanding the existing hotel and the casino. There were five additional scaffolds of similar design in use at the site. The scaffolds were of different configurations and did not have any specifications or proper engineering drawings. Imperial Pacific International, LLC was both the owner of the hotel and the general contractor (GC) for the expansion project. The failed scaffold involved in this incident was used multiple times at the site.

All of the scaffolds in use at the site were similar and resembled a Needle Beam Scaffold. The scaffold platform consisted of a framing, with one end attached directly to the building beams on the same level as the platform, and the other end suspended by four cables that were hung from the building beams and columns on the higher floors. At the time of the collapse, the scaffold was attached to the hotel fourth floor beam and the scaffold platform was loaded with material. Additionally, there were three employees on the scaffold. There was a garden located on the third floor and the failed scaffold fell onto the garden. The failed platform and its location are shown in Figures 1 to 3.

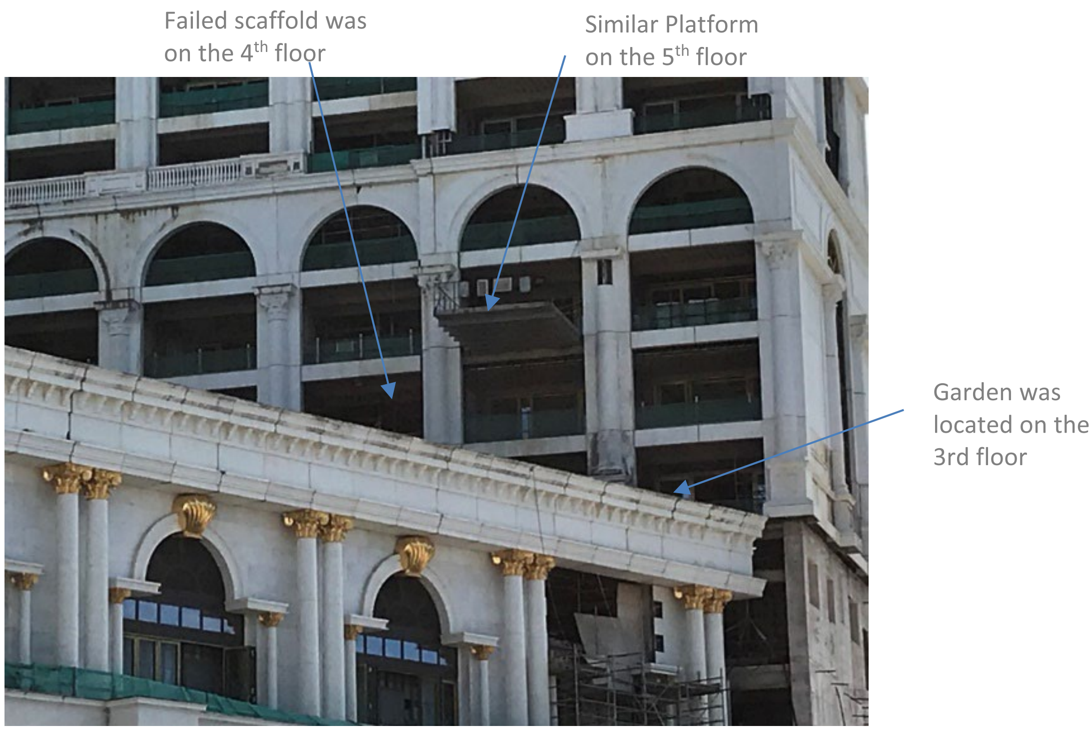

Figure 1 – Hotel and location of failed platform

Figure 2 – Failed scaffold with material

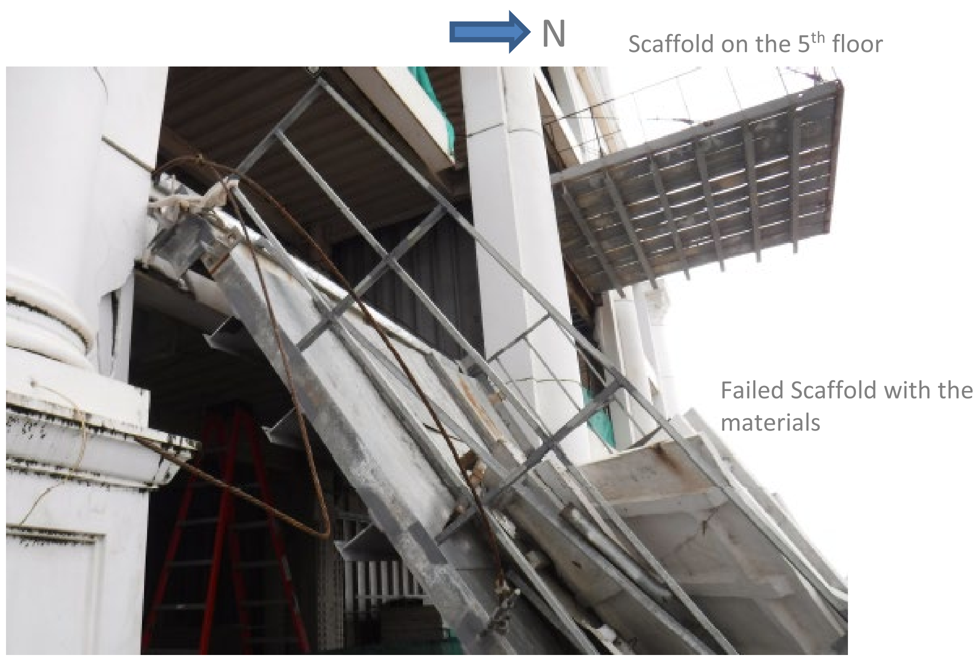

Figure 3 – Failed scaffold

Another view of the hotel and the third floor where the garden was located are shown below in Figures 4 and 5.


Figure 4 – Another view of the hotel

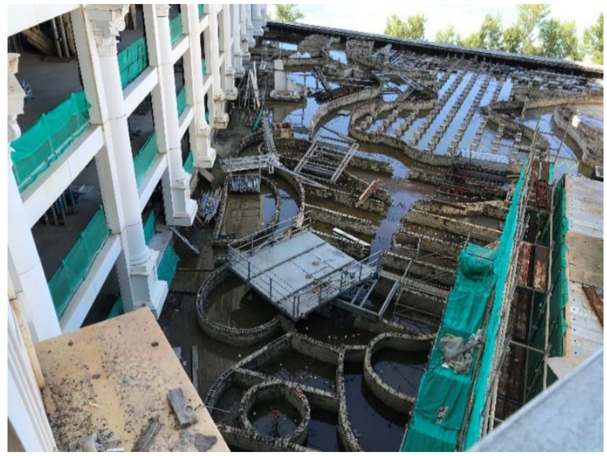
Figure 5 – 3rd floor where garden was located

The scaffold was used for transferring material, mainly granite reinforced concrete (GRC) panels. Once the scaffold was attached to the building, a crane was used to transfer material from the ground to the platform. The employees moved the material from the scaffold to the hotel floor. Each scaffold was used at multiple locations. Once the material transfer was completed at a location, the contractor disassembled the scaffold and used a crane to move the scaffold components to a new location where it was reassembled by the GC. More photographs of the similar scaffolds at the site are shown below in Figures 6 to 9.


Figure 6 – Similar scaffold


Figure 7 – Similar scaffold

Figure 8 – Similar scaffold

Figure 9 – Similar scaffold

3. Scaffold Details

The scaffold sketch prepared by the contractor showed the scaffold dimensions of 5000 mm (16'-4 ¾") long and 3800 mm (12'-5 ½") wide. The scaffold framing was made of H-beams and L-beams. The H-beams were in the transverse direction with spacing shown as 2 feet 4 inches and were connected to the L-beams. The L-beams were along the perimeter of the platform. The section details or the engineering properties of the H-beams or L-beams were not included in the contractor's drawing.

One end of the scaffold framing was supported to a concrete beam of the hotel, with the support connections assembled and welded on site, and the farther side was supported by four cables that were connected back to the building on the upper floors. The support structural details or cable connection details were not included in the contractor's drawing. Sketches prepared by the contractor, along with the railing details are shown in Figures 10 and 11 below.

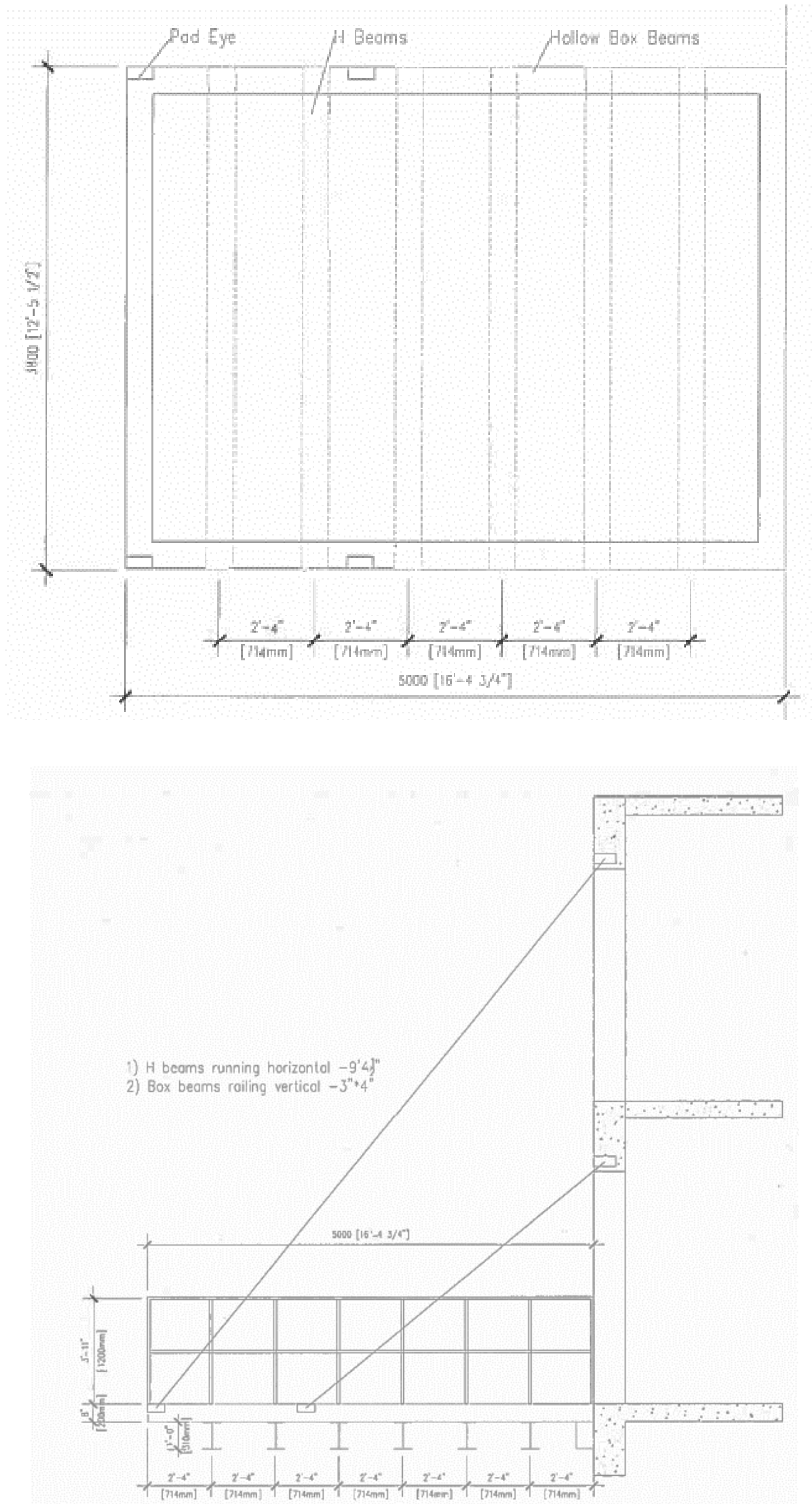

Figure 10 – Drawing prepared by the contractor

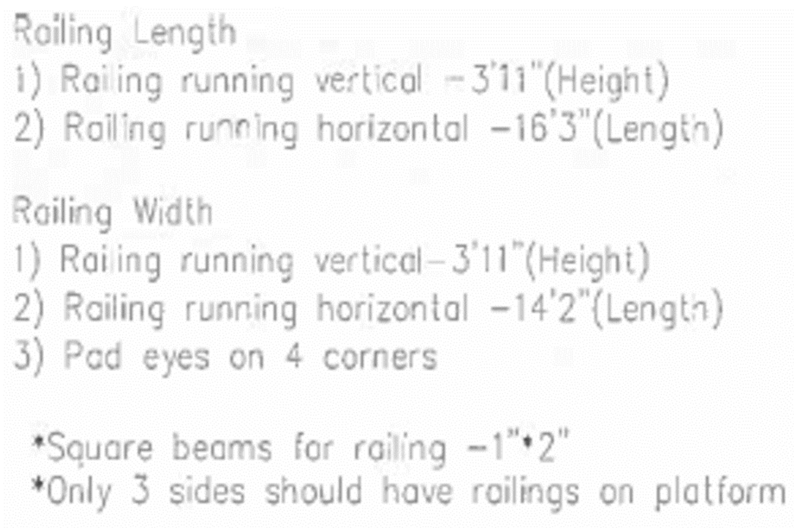

Figure 11 – Railing details in the drawing

The scaffolds at the site were not of the same size as shown in the drawing and the one that failed was 16.67 feet (200 inches) long and 14.67 feet (176 inches) wide. The H-beams in the transverse direction were spaced approximately 2 feet 5 inches apart and it had a depth of 9 inches and a width of 4.5 inches. The thickness was approximately 1/3 inches. The angle beams to which these H-beams were connected were of 6.25"x6.25"x1/3" in size. These angle beams were along the perimeter edge of the platform frame. The scaffold was mounted on the fourth floor of the hotel. Two of the cables were wrapped around the hotel fifth-floor beam and columns, and two were wrapped around the sixth-floor beam and columns. The cable connection to the scaffold are marked as connections 1, 2, 3 and 4 in Figure 12 below.

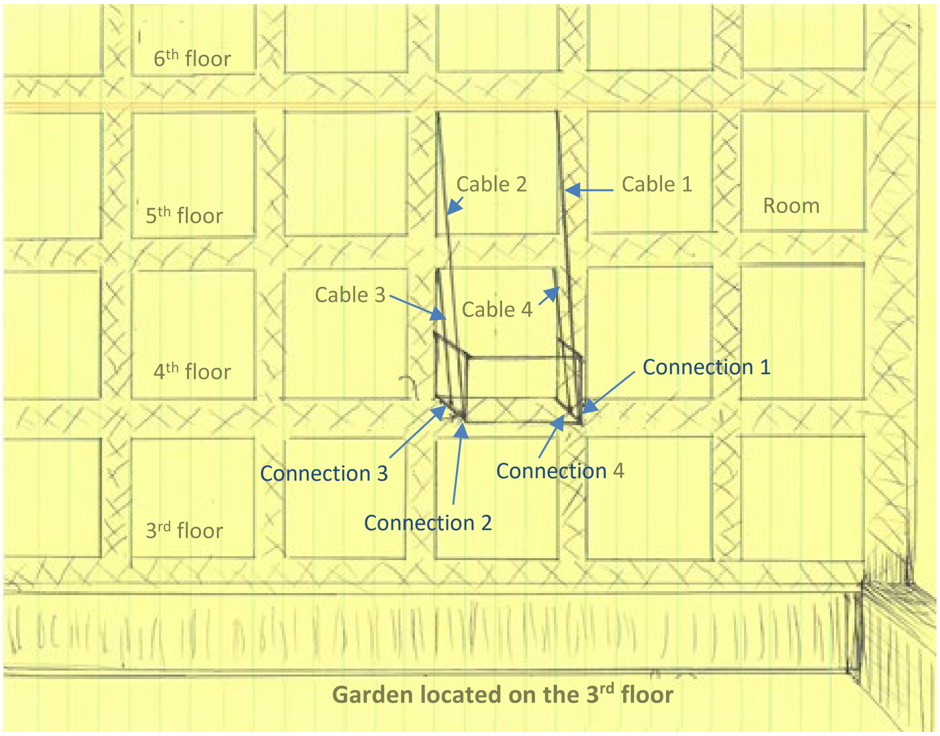

Figure 12 – Scaffold attachment schematic

A crate was used to carry the material. The crate was 118 inches long, 82 inches wide and 59 inches high and was filled with GRC. After the failure, the weight of the scaffold was weighed at the site to be 1,800 kg (approximately 4,000 pounds). The weight of the material on the failed platform was weighed to be 5,400 kg (approximately 12,000 pounds). The crate and the GRC panels can be seen in Figures 13 to 16.

Figure 13 – Crate and GRC panels

Figure 14 – GRC panels

Figure 15 – GRC panels

Figure 16 – GRC panels

The contractor did not have a detailed drawing for the scaffold or for how the scaffold should have been supported. A scaffold drawing shown in Figure 10 was prepared by the contractor, but it did not have the connection details or complete engineering properties of the members. The photographs of the attachment of the scaffold to the building concrete beam are shown in Figures 17 to 22.

Figure 17 – Failed scaffold

Figure 18 – Connection to the hotel beam (east support)

Figure 19 – Connection to the hotel (east support)

Figure 20 – Connection to the hotel (east support)

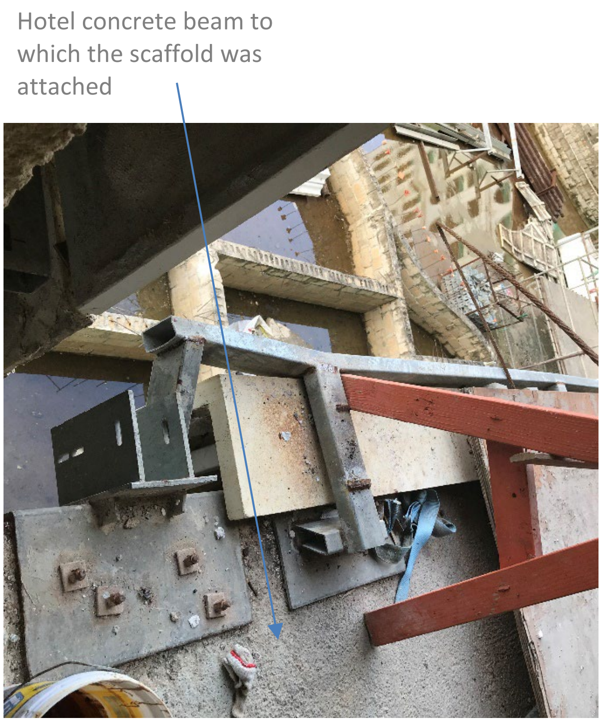

Figure 21 – Connection to the hotel (west support)

Figure 22 – Connection to the hotel (west support)

The cables that were being used were steel 7 x 1 guy wire, ½ inch diameter. The cables were wrapped around beams and columns without protection. The size of the cable and how the cables were wrapped around the beams and columns at the site are shown in Figures 23 to 26.

Figure 23 – Cable size

Figure 24 – Cable wrapped around hotel beam and column

Figure 25 – Cables wrapped around hotel beam and column

Figure 26 – Cable wrapped around hotel beam and column

4. Structural Analysis

The scaffold structure was modeled using STAAD.Pro software. For the transverse beams, W10x19 section (d =10.20 inches; bf = 4.02 inches; tf = 0.40 inches and tw = 0.25 inches) was selected. L6x6x3/8 was selected for the exterior beam to which the transverse beams were attached.

Depending upon the steel grade, the structural shapes would have had a yield strength of 36 kips per square inch (ksi) to 50ksi. Structural shapes of ASTM A36 steel has a minimum yield strength of 36 ksi and ASTM A992 has a minimum yield strength of 50 ksi. The drawing prepared by the contractor did not have the engineering properties for the structural shapes. For both structural steel shapes (transverse beams and the edge beam), a minimum yield strength of 36 ksi (36,000 psi) was assumed in the model.

The 7 x 1 steel guy wire was modeled as a 0.5 inches diameter steel cable. The failed cable was examined by OSHA Salt Lake Technical Center, and their report is attached as an Appendix. The quality of the steel of the cables that were being used was not determined. From the report, the cable would have had a maximum breaking tensile strength of 26,900 pounds. The cables that were being used were corroded and deteriorated. To account for the condition of the cable, a 40 percent reduction in breaking tensile strength was assumed in the structural model. Thus, the maximum breaking tensile strength for the cable was assumed as 26,900x0.60 = 16,140 pounds.

The contractor did not have a detailed drawing to show how the scaffold should have been supported. The two connections between the scaffold framing and the hotel concrete beam was modeled as a simply supported connection, which restrains the horizontal and vertical movement at those locations. Railings were modeled using HSS 2x2x0.188.

The total weight of the structural members that were modeled was calculated from the computer model. Additional dead load to account for the top plate and other non-structural components were then added to the model as uniform distributed load on the transverse beams, so that the weight of the scaffold was equal to the measured weight in the field.

At the time of the incident, the platform was loaded with 12,000 pounds of material. There were also three employees on the platform. The weight of each employee was assumed to be 200 pounds (the weight of each employee at 175 pounds and the weight of tools/equipment carried by each employee at 25 pounds). Thus, the total imposed load that was on the platform at the time of failure was approximately 12,600 pounds.

In the model, cable connections were assumed to be properly attached following the industry standard. The cable breaking strength was assumed as 16,140 pounds. The live load (imposed load) on the platform was taken as 12,600 pounds, which was the actual imposed load on the platform at the time of the incident. To make the model simple, the live load (imposed load) was assumed as a uniformly distributed load, equally distributed on the six transverse beams over a length of seven feet, the width of the crate. The live load on the transverse beam was computed as 12600/(6x7) = 300 pounds per foot. The computer model from STAAD.Pro is shown in Figure 27 below.

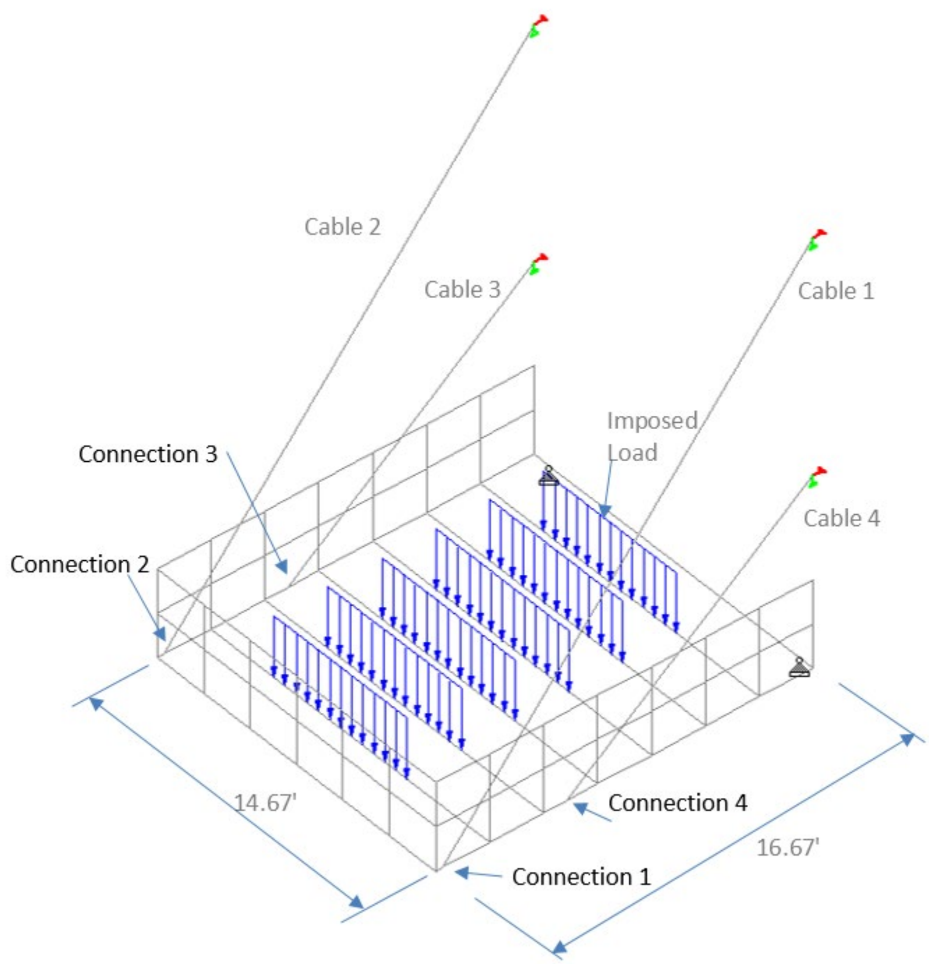

Figure 27 – Computer model for analysis

Four load combination cases were considered. The cables were modeled as tension only members.

Case 1: Dead Load (D.L.) + Live Load (L.L.)

The self-weight of the scaffold (dead load) and the imposed load (live load of 300 pounds per foot over a length of seven feet on the six transverse beams, computed above) were used without additional factors. From the STAAD.Pro analysis of the model, the tensile force in the cables marked 3 and 4 was 6,400 pounds for the D.L.+L.L. combination, which is below the breaking strength of the cable. The stresses in the transverse beams and edge beam were below the yield stress of 36 ksi.

Case 2: 1.2 times Dead Load (D.L.) + 1.6 times Live Load (L.L.)

For the factored loading combination of 1.2 D.L.+ 1.6 L.L., the maximum tensile force in the cables was 9,600 pounds, which is below the breaking strength of the cable. The stresses in the members of the platform frame were also below the yield stress of 36 ksi.

Case 3: Dead Load (D.L.) + 4 times Live Load (L.L.)

In this combination, a live load factor of four was applied to the live load of 300 pounds per foot computed above. Thus the live load on the platform was assumed as 4x300 = 1200 pounds per foot over a length of seven feet on the six transverse beams. From the STAAD.Pro analysis, the tensile force in the cables nearer to the building, cables 3 and 4, was 21,400 pounds, which is greater than the breaking tensile strength of 16,140 pounds. Also, the maximum combined stress in the perimeter edge beam was 45.0 ksi, higher than the assumed yield stress of 36 ksi. The scaffold system did not satisfy the scaffold capacity requirement of CFR 1926.451(a)(1).

Case 4: Dead Load (D.L.) + 6 times Live Load (L.L.)

In this load combination, a multiplication factor of six was applied to the live load. Thus the live load was 6x300 = 1800 pounds per foot acting over a length of seven feet on the six transverse beams. From the analysis, the tensile force in the cables 3 and 4 was 31,400 pounds, which is greater than the cable breaking strength of 16,140 pounds. The cables used for supporting the scaffold was not capable of supporting, without failure, six times the maximum intended load applied. The cables that were supporting the scaffold, did not satisfy the OSHA requirement of CFR 1926.451(a)(3).

5. Discussion

The four cables that were used to support the failed scaffold were deteriorated. The cables and connections were severely corroded and the cables were wrapped around a beam with relatively sharp corners. There was no padding or protection for the cable wrapped around the columns and beams. The rope clips were not installed properly. The scaffold was not attached to the building beam with proper engineering drawing or design. The inspection of the failed scaffold showed that two cables nearer to the building (cable 3 and cable 4) slid through the connections, and cables farther to the building (cable 1 and cable 2) snapped and failed.

OSHA's engineering analysis showed that the two cables nearer to the building (cables 3 and 4) were carrying more load than the two cables (cables 1 and 2) farther away. Based on the inspection and analysis, it is believed that the two cables nearest to the building (cables 3 and 4) became loose and the cables slid through the connections, thereby becoming ineffective. After cables 3 and 4 became ineffective, more load was transferred to cables 1 and 2 and to the supports attached to the building beam. Cables 1 and 2, along with the supports failed, leading to the collapse of the scaffold. Three employees and the materials fell to the lower floor.

29 CFR 1926.451(a)(6) requires scaffolds to be designed by a qualified person, and to be constructed and loaded in accordance with that design. The scaffold as constructed was similar to a Needle Beam Scaffold, and the scaffold was assembled and erected by the contractor without using proper engineering drawings. There was no engineering design and the safe loading capacity was not available.

29 CFR 1926.451 (a)(1) requires that each scaffold and scaffold component to be capable of supporting, without failure, its own weight and at least four times the maximum intended load applied or transmitted to it. The contractor did not determine the safe loading capacity or whether the scaffold satisfied the CFR 1926.451 (a)(1) requirement. Based on our analysis, the scaffold as built did not satisfy this requirement.

29 CFR 1926.451(a)(3) states "*Each suspension rope, including connecting hardware, used on non-adjustable suspension scaffolds shall be capable of supporting, without failure, at least 6 times the maximum intended load applied or transmitted to that rope*." From our analysis, the cables that were supporting the scaffold did not satisfy this requirement.

From our analysis, the geometry and configuration of the platform were not contributing factors to the collapse.

More photographs of the failed platform and the cables are shown in Figures 28 to 35. The compliance officer collected the failed cables and sent them to the OSHA Salt Lake Technical Center for further examination. Their investigation report is in Appendix and has more details on the failed cables and the cable connections.

Figure 28 – Failed scaffold

Figure 29 – Failed scaffold

Figure 30 – Failed cable connections

Figure 31 – Failed cable connections

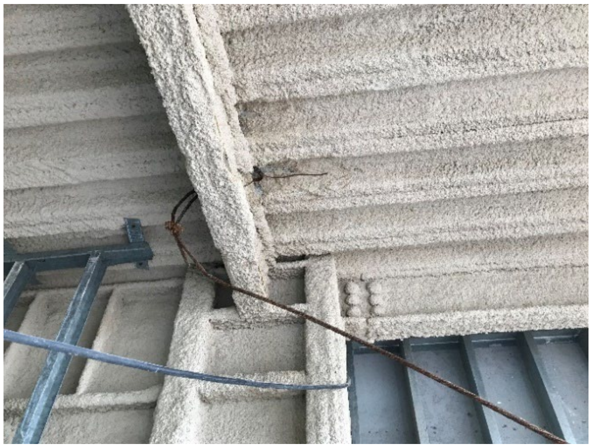

Figure 32 – Failed cable connections

Figure 33 – Failed cable connections

Figure 34 – Failed cable connections

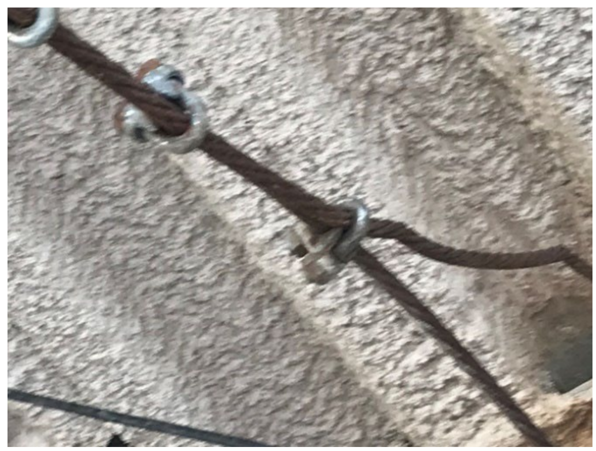

Figure 35 – Cable with kink that was used to support a scaffold on the fifth floor

6. Conclusions

1) The scaffold platform, as designed and constructed, did not meet OSHA's requirement that it be capable of supporting, its own weight and at least four times the maximum intended load without failure.
2) The scaffold platform as constructed was similar to a Needle Beam Scaffold, and was assembled and erected by the contractor without meeting OSHA's scaffolding requirements. The contractor did not have a proper engineering design and thus the scaffold was not constructed and loaded in accordance with a design.
3) The contractor had not determined the safe load carrying capacity of the scaffold as erected. The scaffold was used by employees and was loaded with material without knowing the safe load capacity of the scaffold, as there was no drawing or manual stating the safe load capacity of the scaffold. The scaffold was loaded with material weighing 5,400 kg (approximately 12,000 pounds) and three employees were standing on the platform when the scaffold failed.
4) The scaffold structure was built similar to a Needle Beam Suspended Scaffold and the cables used for supporting it did not satisfy the OSHA requirement that suspension ropes shall be capable of supporting, without failure, at least six times the maximum intended load applied or transmitted to that rope.
5) Post-incident examination of the failed cables revealed that the cables and connections were corroded and that the cables were wrapped around a beam with relatively sharp corners without proper protection. The rope clips were not installed properly. These factors also contributed to the collapse.

7. Appendix

(Report from Salt Lake Technical Center)

Report Date: 26 May 2020
Establishment: Imperial Pacific Resort
Inspection Number: 1456644
Compliance Officer: Pologa Setu
Area Office: Honolulu
Region: 9
SLTC Investigator: Daniel T Crane

Examination of guy cables F01321

A scaffold, approximately16 ft x 12 ft, was located on the 4th floor of a hotel on Saipan Island. The scaffold framing was made of I beams and L beams. The I beams were in the transverse direction, spaced approximately 2 ft – 4 in. apart and were connected to the L beams, which were on the edges. One end of the scaffold was attached to the building and the further side was supported by four cables that were connected back to the building.

Two of the cables were wrapped around the hotel fifth floor beam and columns and two were wrapped around the sixth floor beam and columns. The cable connection to the scaffold are marked as 1, 2, 3, and 4 in the attached sketch (scaffold mounting). Two of the cables supporting the scaffold failed, the other two came out loose and the scaffold collapsed. Three employees were injured. At the time of the collapse, the scaffold was loaded with material.[1]

Five sections of guy cable were submitted to the Salt Lake Technical Center for evaluation.

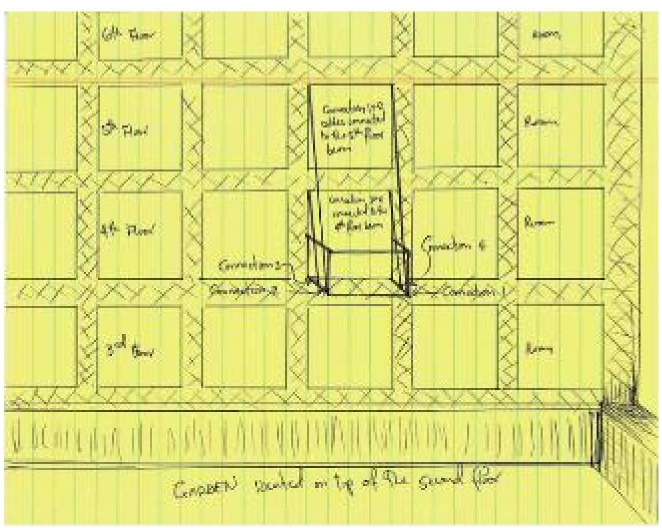

Figure 1: Diagram of the scaffold mounting on the hotel, showing the relative locations of the four cables supporting the platform.

[1] Description excerpted and diagrams from compliance officer communication, 4 February 2020

Figure 2: Sample 1 - Cable sample from the cable attached to the damaged scaffold Connection 1 (see Figure 1) Note the deformed ends at the left. Also note that the cable clips are installed improperly.

Figure 3: Sample 2- Cable sample from the cable attached to the damaged scaffold Connection 2 (see Figure 1). The sample was wrapped around the beam before it broke.

Figure 4: Sample 3A - Cable sample from the cable attached to the damaged scaffold Connection 3 (see Figure 1)

Figure 5: Sample 3B – Cable from scaffold Connection 3 (see Figure 1). The sample was the piece of cable left on the beam where Connection 3 was anchored to the building.

Figure 6: Cable sample from the cable attached to the damaged scaffold Connection 4 (see Figure 1). Note that all of the wire ends are cut.

The cable was a steel 7 x 1 guy wire. The mean diameter was 0.5184 in. The mean diameter of the individual wires was 0.1660 in. This is consistent with ½ in. wire. Depending upon the quality of the steel, the cable would have had a tensile strength in the range between 12,100 lb to 26,900 lb. The quality of the steel was not determined.

Figure 7 shows the failed wire ends in Sample 1. The cable was extremely corroded, as were all of the submitted samples. The mode of failure of the wires was corrosion assisted brittle failure. The arrows in Figure 7 point to several of the broken wires. Also contributing to the failure was bending around a small radius. The bending of the wire ends, seen at the right of Figure 7 occurred as a result of bending around a small radius.

Figure 7: Failed end of Sample 1. The white arrows point to wire ends that failed in corrosion-assisted brittle failure. Also note several of the wires were bent around a small radius, which contributed to the failure.

Figure 8 shows the failed end of Sample 2. The cable was extremely corroded. The mode of failure was mixed, the cable shows some necking as noted. Necking is typical of ductile failure under tensile load. However, the individual ends of the wires show terminations typical of brittle failure.

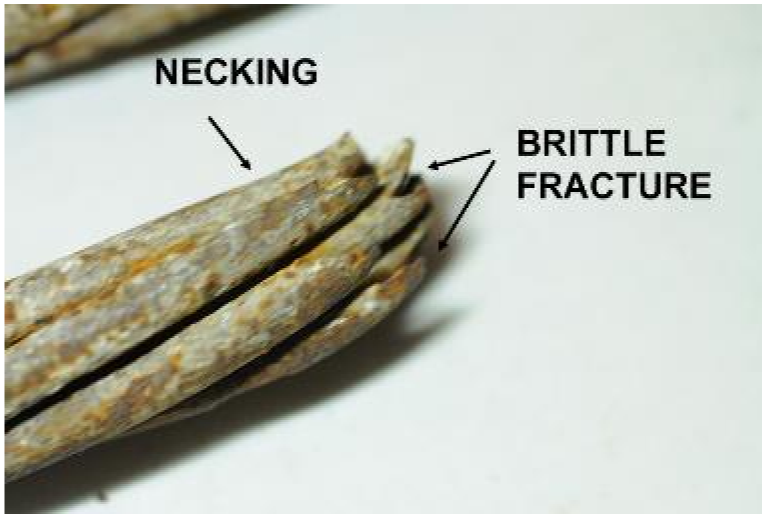

Figure 8: This is one of the ends of Sample 2. The overall cable showed some necking due to tensile failure. However, the individual wires demonstrate fracture typical of brittle failure.

Figure 9: Failure of one of the wires in Sample 3A. The longitudinal crack is typical of corrosion-assisted brittle failure.

The wire shown in Figure 9 has a crack along the length. Such a failure is typical of corrosion assisted cracking. Such occurs when the wire rope is under tension.

Figure 10 is representative of the surface corrosion present on all of the submitted samples. All of the samples were severely corroded.

Figure 10: Example of the corrosion on the wire rope. Sample 4

Figure 11: A broken wire on Sample 4 showing brittle failure with corrosion internally.

Figure 12 shows Connection 4c, which was wrapped around a beam with relatively sharp corners. No padding or protection was present.

Figure 12: Broken wire rope where it went over a beam. There was no protection for the wire guy rope.

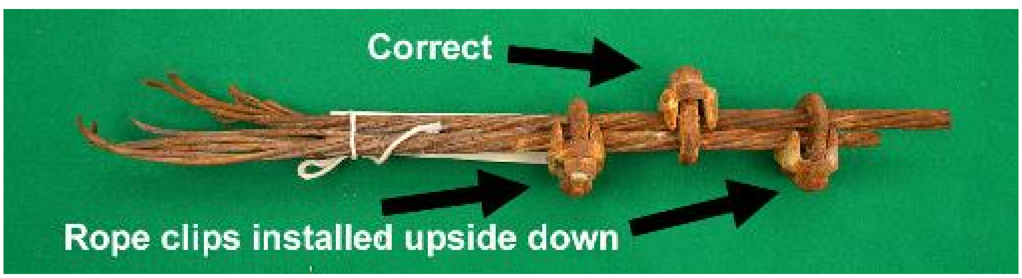

Figure 13: Sample 1. The rope clips are not installed correctly. The "U" shape of all of the clips must be installed on the short end of the wire rope.

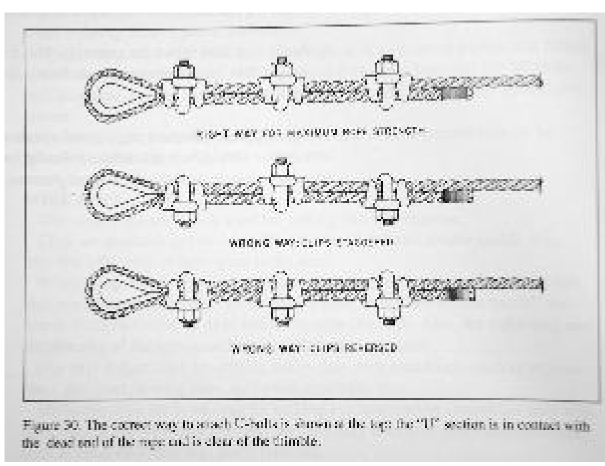

Figure 14: Figure 30 from Wire Rope Technical Board Handbook showing the use of wire rope clips. Also note how thimbles are placed.

Figure 13 shows the improper use of rope clips. 29 CFR 1926.251(c)(5)(i). Figure 14 shows the proper use of rope clips.[2]

Discussion

The general condition of the guy wire samples was that they were severely corroded. The observed failures on 4 of the 5 submitted samples was at locations where the wire was bent over a small radius. These small radius surfaces were over beams, or in loop to loop connections of the wire ropes.

While the general failures appear to be mostly brittle, there was, as noted in Figure 8, some necking typical of tensile failure. However, even in that sample, the failure surface had a brittle nature as evidenced by the appearance of inter-granular fracture.

Insufficient evidence was presented to SLTC to determine the actual stress on each of the samples. However, the corroded condition of the wire guy ropes severely diminished the breaking strength. In addition, the samples were not in a condition for meaningful tensile testing. Therefore, no strength analysis was performed.

The most significant factors available to examine are the corrosion and small radius bending without protection of the rope over those edges.

Wire ropes are made of steel and steel under stress in corrosive atmospheres can undergo stress corrosion cracking (SCC). The inter-grain boundaries of the steel become weakened by the introduction of impurities and corrosion. This weakens the steel. When this happens, the steel fails in an inter-granular manner. Figures 7, 9 and 11 show the blocky nature of the breaks. Figure 9 also shows a fracture running down the wire. Figure 11 shows a broken wire from Sample 4 with brittle fracture. The amount of corrosion in the fracture shown in Figure 11 suggests that it was present before the incident. Note that the fractures were full of corrosion.

The loss of a single wire in a 7 x 1 guy rope lessens the effective strength by more than 14% (1/7). The actual loss of strength will be more because the wires work in concert to be stronger than the sum of the individual wire strengths.

Small radius bends are stress- multipliers. That is, any stress applied to the wire rope is locally multiplied because of the small area of application.

In the case of connection to beams and other anchors, the wire rope must be protected against the small radius and any potential cuts in the wire that could occur.[3]

For loop to loop connections, it is preferred that the wire rope loops be protected using thimbles in order to lessen the rope-to-rope point force and abrasion that can occur. Figure 14 shows how thimbles are installed in wire rope loops.

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[2] Wire Rope User's Manual, Fourth Edition, Wire Rope Technical Board, 2005
[33] 29 CFR1926.251(c)(9)

The amount of corrosion on the submitted wire ropes and the possibility of a pre-existing failed wire are sufficient for removal from service.

Conclusion

The loss of strength to the wire rope guy cables due to corrosion and bending over small radius edges and other wires contributed to the failure.