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Collapsed Towers Evaluation / Investigation Final Report

Project:
WO-A-0104 DABS 220 kV Transmission Line Tower Inspection

Date:
June 6, 2016

PRESENTED TO

**United States Agency for International Development (USAID)
Office of Economic Growth and Infrastructure (OEGI)**

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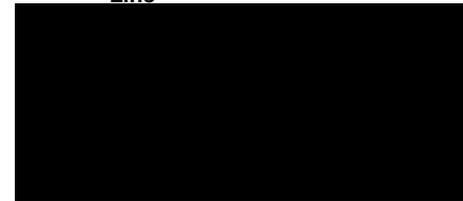
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Shash Darak
Kabul, Afghanistan

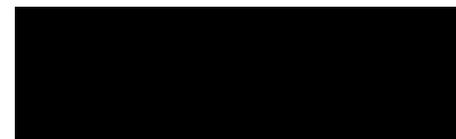
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BACKGROUND

Six transmission towers have failed in the area north of Kabul in recent months.

Under a separately funded contract, a contractor to the Ministry of Energy and Water (MEW) / Da Afghanistan Breshna Sherkat (DABS) completed the construction of the 220 kV Double Circuit Double Conductor transmission line from Pul-e-Khumri to Naibabad (Baghlan Province) in December 2013. Two transmission towers on this line failed or collapsed, one in January 2016 and one in February 2016.

In February and March 2016, an additional four towers failed on the 220 kV Double Circuit Single Conductor line from Pul-e-Khumri to Kunduz.

OBJECTIVE

The objective of this work order is to provide a quick and independent professional evaluation of the cause of failure or collapse of the six towers. This analysis should provide an answer to the question of whether the failure/collapse of the towers was caused by an explosive ordinance or was a structural failure due to low quality of materials or workmanship.

DESCRIPTION OF LINES

The tower failures occurred on two different lines, the details of which are provided below:

Pul-e-Khumri – Naibabad:

- 220 kV Double Circuit, Double Conductor, ACSR size unknown

Pul-e-Khumri – Kunduz

- 220 kV Double Circuit, Single Conductor, ACSR size unknown
- Lattice tower framed for double circuit (both circuits installed)

The towers are numbered in ascending order from North to South.

DABS reported that both of these lines were designed and built by KEC, an engineering and construction company.

Locations of the six towers are show in Appendix A.

INVESTIGATION METHOD

The investigation is based on very limited information supplied by DABS. This information includes photographs of some of the towers, samples of steel members from two of the towers, weather data obtained online, seismic event data obtained online, and tower locations as plotted on Google Earth. Steel pieces from two towers were sent to a material testing laboratory in Kabul, Afghanistan and another laboratory in Peshawar, Pakistan for analysis of tensile yield strength and metallurgical/chemical analysis.

The investigation was hampered by the lack of information. Requests to DABS for original construction drawings and specifications were not answered and the drawings and specifications have not yet been supplied. The following information was used in the analysis:

- GPS location, general location, and structure number of failed towers - Information supplied by DABS
- Date and time of failure - Information supplied by DABS
- Location of other failed towers and dates, including confirmation that none of the towers were adjacent to each other - Information supplied by DABS
- Weather information, including data showing that weather at the time of failures was not severe, with an average temperature of 4°C – information included in Appendix B.

- Detailed photographs of the failed towers, including views of the towers on all sides were requested from DABS. Some photos were supplied.
- DABS was requested to supply Quality Control (QC) documents and inspection reports from their records. The QC documents were not available from DABS. Attempts were made to obtain the documents from MEW, but were unsuccessful.
- Per DABS, the towers were designed and installed by KEC.
- Design calculations and conductor/line specifications were created by KEC, but were not made available to Tetra Tech for review.
- DABS has repaired all towers, and they are back in service.
- There was no fighting or military actions known to have occurred near the towers at the time of the failures.
- At the direction of USAID, there was no communication with the original construction contractor or with any local nationals, other than the DABS Chief Executive Officer (CEO) and Operations Manager.

DESCRIPTION OF FAILED TOWERS

Tower No. 494 – 220 kV Double Circuit, Double Conductor per Phase

Line: Naibabad to Pul-e-Khumri

Total Length: 164.189 km

Date of Failure - 2/2/2016

There were no photos of the entire tower provided. There is a photo of a tower leg showing a torch cut through the angle iron leg near the concrete foundation. This is obvious sabotage intended to cause tower failure. There are no other photos that might have shown the tower's ultimate failure mode.

Tower No. 489 – 220 kV Double Circuit, Double Conductor per Phase

Line: Naibabad to Pul-e-Khumri

Total Length: 164.189 km

Date of Failure - 1/26/2016

There were no photographs provided for this tower. Failure mode is unknown.

Tower No. 544 – 220 kV Double Circuit, Single Conductor per Phase

Line: Kunduz - Pul-e-Khumri

Date of Failure - 2/9/2016

Total Length: 109.996 km

There is clear evidence from the photographs that tower legs were destroyed by an explosive charge. This explains the cause of the failure. Samples of tower steel were collected and tested for yield strength, ultimate strength, and elongation.

Tower No. 500 – 220 kV Double Circuit, Single Conductor per Phase

Line: Kunduz - Pul-e-Khumri

Date of Failure - 3/3/2016

Total Length: 109.996 km

Photographs were provided which show the tower folded over with the conductors on top. Failure occurred at the fourth panel. Samples of tower steel were collected and tested for yield strength, ultimate strength, and elongation. There is no further information available on this failure.

Tower No. 486 – 220 kV Double Circuit, Single Conductor per Phase

Line: Kunduz - Pul-e-Khumri

Date of Failure – No date was provided

Total Length: 109.996 km

There were no photographs provided for this tower. Failure mode is unknown. DABS reported this failure on a spread sheet documenting tower details.

Tower No. 484 – 220 kV Double Circuit, Single Conductor per Phase

Line: Kunduz - Pul-e-Khumri

Date of Failure – 2/21/2016

Total Length: 109.996 km

There were no photographs provided for this tower. Failure mode is unknown. DABS reported this failure on a spread sheet documenting tower details.

LABORATORY TESTS

Strength Testing

Steel member pieces from towers 500 and 544 were supplied by DABS. These samples were sent to Build Afghanistan Engineering Services, (BAES), and a testing laboratory in Kabul where the steel was tested for tensile strength, ultimate strength, and elongation at failure. For comparison purposes, test results of similar angle iron sizes from the DABS/USAID project Arghandi – Ghazni (ARG-GZN) Transmission Line are also included and presented in Table 1.

Tests showed similar yield and ultimate tensile strengths, but the samples from the failed towers, 500 and 544, had lower elongation percentages – meaning the failed tower steel is more ductile, versus a more malleable steel being used in the ARG-GZN T/L. ASTM A36, Table 3 Tensile Requirements states that the minimum elongation is 20%.

Design and QA/QC documents were not available, making it impossible to determine if the steel was per the contract specifications. It is also unknown what parameters were used to design and test the towers.

Table 1. Strength Test Results

Failed Tower 544, Tajikistan Line					
Angle Test No.	Mark No.	Section (mm)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	None found	110 * 110 * 8	367.293	674.058	13.7
2	None found	110 * 110 * 8	360.932	568.447	15.3
Testing performed by BAES of Kabul on March 29, 2016.					

Failed Tower 500, Tajikistan Line					
Angle Test No.	Mark No.	Section (mm)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	None found	50 * 50 * 6	482.741	586.224	10
2	None found	50 * 50 * 6	477.363	599.757	12.5
3	None found	50 * 50 * 6	477.29	666.19	14.2
4	None found	50 * 50 * 6	427.228	523.707	12
Testing performed by BAES of Kabul on March 29, 2016.					

The following test results are provide for comparison purposes. Tested samples are from towers on the Arghandi – Ghazni Transmission Line.

Tower DDE, Arghandi-Ghazni Line					
S. No.	Mark No.	Section (mm)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	C432E287	HT (100X100X7)	401	561	31
2	C432E40	MS (70X70X5)	291	465	31
Testing performed by KEC QA of Nagpur, India.					

Tower DD, Arghandi-Ghazni Line					
S. No.	Mark No.	Section (mm)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	C432D135	MS (100X100X7)	290	464	29
2	C432D41	MS (50X50X5)	298	476	31
Testing performed by KEC QA of Nagpur, India.					

Tower DC, Arghandi-Ghazni Line					
S. No.	Mark No.	Section (mm)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	C432C391	HT (100X100X7)	436	564	27
2	C432C51	HT (60X60X5)	489	595	28
Testing performed by KEC QA of Nagpur, India on 8June2015.					

Tower DB, Arghandi-Ghazni Line					
S. No.	Mark No.	Section (mm)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	C432B34	MS (100X100X7)	335	459	34
2	C432B17	HT (65X65X5)	457	571	27
Testing performed by KEC QA of Nagpur, India on June 8, 2015.					

Tower DA, Arghandi-Ghazni Line					
S. No.	Mark No.	Section (mm)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	C432A92	HT (110X110X9)	446	575	26
2	C432A483	HT (50X50X5)	470.56	582.67	26.45
Testing performed by KEC QA of Nagpur, India on June 8, 2015.					

250 mPa = 36 ksi = ASTM A36 steel

Elongation: 20% minimum

Metallurgical Chemical Analysis

Samples of tower steel were sent to a laboratory in Pakistan for analysis of the chemical composition of the metal. The chemical composition of the sample were in range with the chemical analysis of Arghandi-Ghazni Transmission Line.

SEISMIC CONSIDERATIONS

Earthquake activity was investigated as a possible cause of tower failure. Seismic events are published on the [Earthquake Track](http://earthquaketrack.com) website, <http://earthquaketrack.com>. There was one event during the time frame of the tower failures that occurred on March 1, 2016. The magnitude of the earthquake was 4.5 on the Richter scale with the epicenter 8 km from Pul-e-Khumri. It is unlikely that an earthquake of this size would cause a tower failure. A list of other seismic events is shown in Table 2 below.

Table 2 – Seismic Activity

Earthquake Data			
Date	Size/description	Location	Depth
1/13/16 12:34 AM	M 5.7 - 34km SSE of Jarm, Afghanistan	36.598°N 70.950°E	239.0 km (148.5 mi)
2/21/16 1:42 PM	M 5.5 - 43km S of Jarm, Afghanistan	36.481°N 70.866°E	174.9 km (108.7 mi)
3/1/16 12:03 PM	M4.5 - 8km N of Pul-e Khumri, Afghanistan	36.024°N 68.706°E	35.3 km (21.9 mi)
3/5/16 3:25 AM	M4.1 - 62 km from Pārūn, Nūrestān, Afghanistan	35.529°N 70.244°E	89.5 km (55.6 mi)

Source: <http://earthquaketrack.com/>

CONCLUSIONS

It is known that a total of six (6) 220 kV lattice steel towers failed on two transmission lines in the Baghlan province of Afghanistan over approximately a one-month period. The first was on January 26, 2016 and the last was March 3, 2016. Two of the towers, 494 and 544, show clear signs of interdiction. Tower 494 had at least one leg which had been cut at the base of the leg just above the concrete foundation. From the photo, it appears that the cut was made with a torch or some other intentional cutting method. Tower 544 was damaged by multiple explosive devices. The weather report provided in Appendix B shows that there were no unusual weather events that could have contributed to the tower failures. The Kunduz Airport weather station was used for this data, as the closest weather station to the tower sites.

Due to very limited information about the remaining towers, it is not possible to determine the root cause of the failures. Strength tests show the failed towers were made of stiffer material than materials being used currently for similar towers on the Arghandi-Ghazni Transmission Line. It would have been useful to compare test results with the specifications and governing codes that were part of the original construction contracts. Several requests were made to DABS for this information, but this information was never received.

Recommendations

More investigation and data are required to determine the root cause of failure for four of the towers. The following is a list of recommended actions needed to make conclusive determination of the failures:

1. Specifications from the original construction contracts are needed. This information should show the design parameters used as a basis for the tower designs. This would allow for review of the tower designs using industry standard software such as PLS Tower
2. QA/QC records or FAT test of the factory productions that show materials used in the towers met or exceeded the specifications.
3. Records of type tests.
4. More detailed photographs of the failed towers.
5. Climbing Inspection of all remaining towers between Pul-e-Khumri and Kunduz, and Pul-e-Khumri and Naibabad, directed by the following outstanding questions:
 - a. Are there any loose, missing, or bent bolts or members?
 - b. Are there any signs of cracking or corrosion of tower members or foundations?

APPENDIX A – PHOTOGRAPHS

PHOTOGRAPHS



Photograph 1: Tower 544, Pul-e-Khumri to Kunduz



Photograph 2: Tower 544, Pul-e-Khumri to Kunduz



Photograph 3: Tower 500, Pul-e-Khumri to Kunduz



Photograph 4: Tower 500, Pul-e-Khumri to Kunduz



Photograph 5: Tower 500, Pul-e-Khumri to Kunduz



Photograph 6: Tower 494, Pul-e-Khumri to Naibabad showing cut leg

APPENDIX B – WEATHER DATA

WEATHER DATA

(P-N) Pul-e-Khumri to Naibabad Line

(P-K) Pul-e-Khumri to Kunduz Line

Tuesday, January 26, 2016 (Tower T-489 (P-N))

Time	01:30	04:30	07:30	10:30	13:30	16:30	19:30	22:30
Weather								
Temp	9 °c	8 °c	9 °c	10 °c	12 °c	13 °c	11 °c	10 °c
Feels Like	9 °c	8 °c	7 °c	9 °c	12 °c	13 °c	11 °c	8 °c
Rain	0.0 mm	0.0 mm	0.0 mm	0.4 mm	1.2 mm	0.0 mm	0.0 mm	0.3 mm
Wind	2 mph NW	1 mph NW	6 mph NW	6 mph W	6 mph NW	4 mph N	2 mph NE	5 mph NNW
Gust	3 mph	1 mph	12 mph	9 mph	7 mph	5 mph	3 mph	7 mph
Rain?	0%	0%	0%	0%	0%	0%	0%	0%
Cloud	79%	60%	51%	99%	15%	13%	95%	100%
Humidity	25%	27%	33%	51%	70%	69%	85%	86%
Pressure	1013 mb	1012 mb	1013 mb	1014 mb	1014 mb	1015 mb	1017 mb	1017 mb

Tuesday, February 2, 2016 (Tower T-494 (P-N))

Time	01:30	04:30	07:30	10:30	13:30	16:30	19:30	22:30
Weather								
Temp	3 °c	2 °c	3 °c	10 °c	14 °c	13 °c	10 °c	8 °c
Feels Like	3 °c	2 °c	3 °c	10 °c	14 °c	13 °c	10 °c	8 °c
Rain	0.0 mm	0.0 mm	0.0 mm					
Wind	1 mph NE	2 mph N	1 mph NW	2 mph N	4 mph NNE	3 mph NNE	2 mph NE	2 mph NE
Gust	3 mph	4 mph	3 mph	2 mph	5 mph	3 mph	5 mph	5 mph
Rain?	0%	0%	0%	0%	0%	0%	0%	0%
Cloud	3%	3%	3%	4%	7%	6%	4%	0%
Humidity	69%	76%	70%	46%	35%	38%	42%	41%
Pressure	1027 mb	1025 mb	1026 mb	1026 mb	1024 mb	1024 mb	1025 mb	1026 mb

Tuesday, February 9, 2016 (Tower T-544 (P-K))

Time	01:30	04:30	07:30	10:30	13:30	16:30	19:30	22:30
Weather								
Temp	11 °c	8 °c	8 °c	11 °c	11 °c	9 °c	6 °c	5 °c
Feels Like	10 °c	7 °c	8 °c	9 °c	9 °c	6 °c	4 °c	3 °c
Rain	0.0 mm	0.5 mm	0.7 mm	0.5 mm				
Wind	5 mph W	4 mph WSW	3 mph WSW	13 mph WNW	9 mph W	11 mph W	8 mph WNW	6 mph WNW
Gust	10 mph	9 mph	4 mph	15 mph	11 mph	13 mph	10 mph	7 mph
Rain?	0%	0%	0%	0%	0%	0%	0%	0%
Cloud	100%	100%	94%	18%	100%	100%	90%	100%
Humidity	38%	46%	53%	50%	50%	64%	73%	79%
Pressure	1019 mb	1018 mb	1018 mb	1017 mb	1017 mb	1019 mb	1023 mb	1024 mb

Sunday, February 21, 2016 (Tower T-484 (P-K))

Time	01:30	04:30	07:30	10:30	13:30	16:30	19:30	22:30
Weather								
Temp	11 °c	9 °c	10 °c	18 °c	22 °c	21 °c	17 °c	12 °c
Feels Like	11 °c	9 °c	11 °c	18 °c	22 °c	21 °c	17 °c	12 °c
Rain	0.0 mm	0.0 mm	0.0 mm					
Wind	2 mph N	2 mph NNW	2 mph NW	3 mph NNW	4 mph N	3 mph NNW	3 mph WNW	4 mph SSE
Gust	4 mph	5 mph	5 mph	3 mph	5 mph	4 mph	6 mph	8 mph
Rain?	0%	0%	0%	0%	0%	0%	0%	0%
Cloud	15%	16%	12%	22%	44%	51%	74%	46%
Humidity	37%	38%	38%	20%	16%	20%	26%	26%
Pressure	1021 mb	1020 mb	1020 mb	1020 mb	1020 mb	1021 mb	1025 mb	1027 mb

Thursday, March 3, 2016 (Tower T-500 (P-K))

Time	01:30	04:30	07:30	10:30	13:30	16:30	19:30	22:30
Weather								
Temp	11 °c	11 °c	13 °c	18 °c	23 °c	22 °c	17 °c	15 °c
Feels Like	11 °c	11 °c	13 °c	18 °c	24 °c	24 °c	17 °c	15 °c
Rain	0.0 mm	0.0 mm	0.0 mm					
Wind	1 mph SW	0 mph NE	1 mph SSE	4 mph NNE	6 mph NNE	5 mph N	3 mph NNW	2 mph SE
Gust	2 mph	0 mph	1 mph	4 mph	7 mph	6 mph	5 mph	4 mph
Rain?	0%	0%	0%	0%	0%	0%	0%	0%
Cloud	24%	31%	52%	14%	5%	8%	9%	5%
Humidity	70%	72%	67%	52%	43%	41%	54%	61%
Pressure	1024 mb	1023 mb	1024 mb	1023 mb	1020 mb	1018 mb	1019 mb	1019 mb

Note: No date given for Tower 486 on the P-K line.

Source: worldweatheronline.com

APPENDIX C – MAP

MAP



Towers on the Pul-e-Khumri to Naibabad Line are represented in green.

Towers on the Pul-e-Khumri to Kunduz Line are represented in red.