Proposed Methods to Prevent Continuous Collapse of Utility Concrete Poles

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Abstract.

From the accidental reporting statistics of utility concrete poles in Thailand, they were often found that lots of continuous collapses of more than one pole occurred from cars, storms or cable lines hooked by falling trees or trucks. This type of failure is induced by the tensile forces through the electric cables to the adjacent poles and cause the consequent collapse. Due to the brittle behavior of concrete, the cracked positions were mostly found near the base of poles due to maximum bending moment. Because the tensile force induced in electric cables occurs from weight above the downed position of collapsed pole. Therefore, the proposed method to prevent this collapse was introduced by reducing the mass of pole above the snapped point, leading to the reduction in tensile force to the adjacent poles, then decreasing the number of collapsed poles respectively. The analytical finite element (FEM) models were employed to determine the optimum position on each type of poles in order that the weight induced above those parts would not be able to transfer adequate forces to topple adjacent poles. Carbon fiber reinforced polymer (CFRP) and steel plates were then introduced to strengthen the existing poles and the poles in future manufacturing process consecutively. The experiments were conducted and compared to the analytical results. It is indicated that the utility poles were strengthened and the tensile forces induced by the weight above the toppled positions could be reduced significantly.

Keywords. -

1. INTRODUCTION

Utility poles used in Thailand have been manufactured by prestressed concrete material which can resist high compressive and bending loads. In conventional design, the utility poles are designed to sustain from the wind speed at or below 96 km/hr. However, lots of continuous collapses were reported from the accidents concerning utility poles e.g. car accidents or strong wind. These result from the poor ductility behavior of concrete as well as the conventional design does not concern the effect of evolved failure induced from the tensile force in cable lines when any poles have been toppled. The higher length from the cracking point the more pulling force is created through the cables to the adjacent poles. The propose of this study is to reduce the tensile force induced in the cable lines by strengthen the utility poles and control the cracking points when they are subjected to the force transferred from the toppled poles. The optimum cracking positions of poles will be determined primarily in order to reduce weight induced beyond when poles are subjected to the pulling force from toppled pole adjacent to them. Thus, tensile forces generated from this weight in cables can be decreased to the next poles respectively. In this study, 2 transmission systems of utility poles are chosen which are 12/24 KV and 69/115 KV. Three height models are studied for 12/24 KV system and two height models of 69/115 KV system are selected according to Metropolitan Electricity of Authority (MEA) standards. The graphical proposed study is shown in figure 1

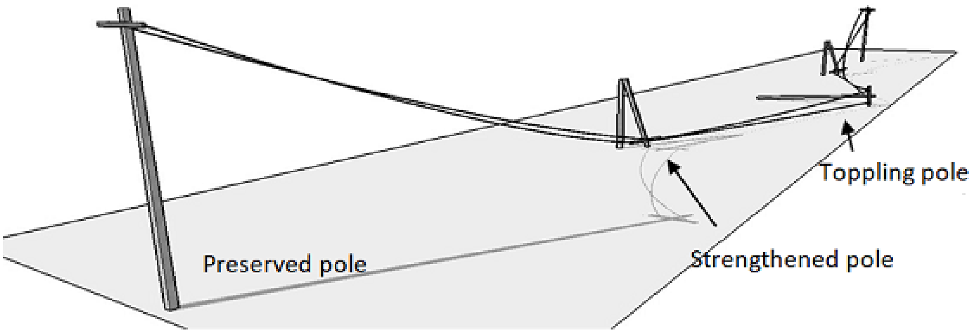

Figure 1 The idea of proposed study.

In order to strengthen the poles to control the cracking positions for each type of utility pole systems, Steel plates are introduced to reinforce the poles in modern design criteria and plate type of Carbon fiber reinforced polymer (CFRP) will be fabricated for the existing poles. The strength and properties of Materials used in this study are indicated in Table 1 for concrete, prestressed wire, stirrup and steel plate grade SS400 while the properties of CFRP are indicated in Table 2.

Table 1 Strength and Properties of Materials

Strength	Materials			
	Concrete	Prestressed wire	Stirrup	Steel plates
Yield (MPa)	-	1570	235	235 ($t \leq 16$mm) 245 ($t > 16$mm)
Tensile (MPa)	-	1226	295	400-510
Compressive (MPa)	44	-	-	-

Young’s modulus (MPa)	31,413	169,655	50,014	50,014

Table 1 Continued

Strength	Materials			
	Concrete	Prestressed wire	Stirrup	Steel plates
Density (kg/m3)	2,400	7,850	7,850	7,850
Poisson’s ratio	0.18	0.30	0.30	0.30

Table 2 Properties of CFRP

Design Thickness (cm)	Ultimate Elongation	Tensile strength (MPa)	Tensile E-Modulus (MPa)
1.2	1.8%	3,100	170,000 MPa

2. FEM MODELS AND ANALYTICAL RESULTS

2.1. FEM models to determine the optimum cracking positions.

In this step of analyses, 5 FEM models of height as stated in Metropolitan Electricity of Authority (MEA) standards were analyzed to obtain the optimum cracking positions when subjected to the pulling force from adjacent downed pole. The models were composed of 12.00 m.GW, 12.00 m. 5 Tm., and 12.35 m. 6.5 T-m for 12/24 KV system and 22.00 m. 18 T-m. and 22.00 m. 25 T-m. for 69/115 KV system. The tensile forces induced from cables line were calculated from the span of 40 m for 12/24 KV system and 80 m for 69/115 KV system respectively. The details of the reinforcements of poles in corresponding with MEA standards are stated in table 3.

Table 3 Details of reinforcements

Model	Prestressed wire	Stirrup	Extra rebars
12.00 m.GW	32 Ø 4mm.		-
12.00 m. 5 T-m	1.8%		4 Ø 25 mm L=5 m. 4 Ø 12 mm L=5 m.
12.35 m. 6.5 T-m	20 Ø 7mm.	Ø 3 mm. @ 30 cm.	-
22.00 m. 18 T-m	36 Ø 7mm		-
22.00 m. 25 T-m	36 Ø 7mm		4 Ø 19 mm L=5 m.

The boundary condition of the bases was assumed to be fixed support. The prestressed forces in prestressed wires were preloaded as well as the pulling forces induced from the cable lines calculated from the weight assumed to act beyond the cracking points of downed pole. The accumulations of heights beyond the assumed cracking position intervals every 1 meter from the base of poles were used to calculate the weights for the utility poles in 12/24 KV system while intervals every 2 meters were used in 69/115 KV system. For an example, the summations of weights of 3, 4, 5, 6, 7, 8, 9, 10 and 10.25 m. from the top of pole were represented the cracking positions at 9, 8, 7, 6, 5, 4, 3, 2, and 1.75 meter from the base of pole for 12.00 m. pole, respectively. When it is required to installed 1.75 m of the pole base underneath the ground, that means the pole is modeled to crack at the base of ground initially and then higher to the upper parts. The weight assumed to generate the tensile force in cable lines for 12.00 m. GW model are shown in Table 4.

Table 4 weights assumed to create tensile force in cable lines for 12.00 GW model

Height from pole base (cracking point) (m)	Weight (kg)	Height from pole base (cracking point)	Weight (kg)
1.75	1,017	5.00	650
2.00	986	6.00	548
3.00	869	7.00	452
400	756	8.00	349
		9.00	251

The effect of surged load from cable lines were also concerned in the analyses by adding the impact factor of 1.3 to the calculations. In each analysis model, when the distances x, y, and z in coordinated system are known, the forces in x, y and z axes which will consequently acted to the cable line position adjacent pole can be calculated as depicted in figure. 2

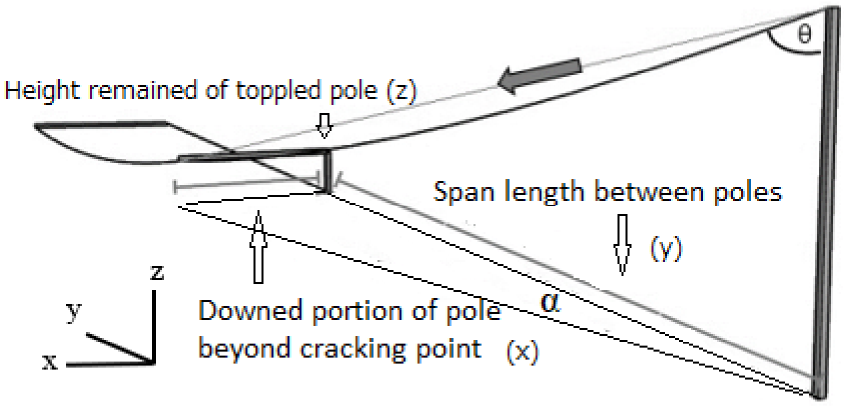

Figure 2 Pulling forces used for the FEM models.

In each analytical model, the stress occurred in each height of pole would be compared to the limit strength of concrete in order to determine the safety factor. When the value of safety factor is greater than 1, it means the pole can sustain the weight of downed portion of adjacent pole induced through pulling load in cable lines. The value of 1 was used to obtain the optimum height of each pole to be strengthened. The heights of pole versus safety factor values were plotted in figure 3 and figure 4 to determine the optimum cracking positions in each utility pole systems where safety factor is equal to 1

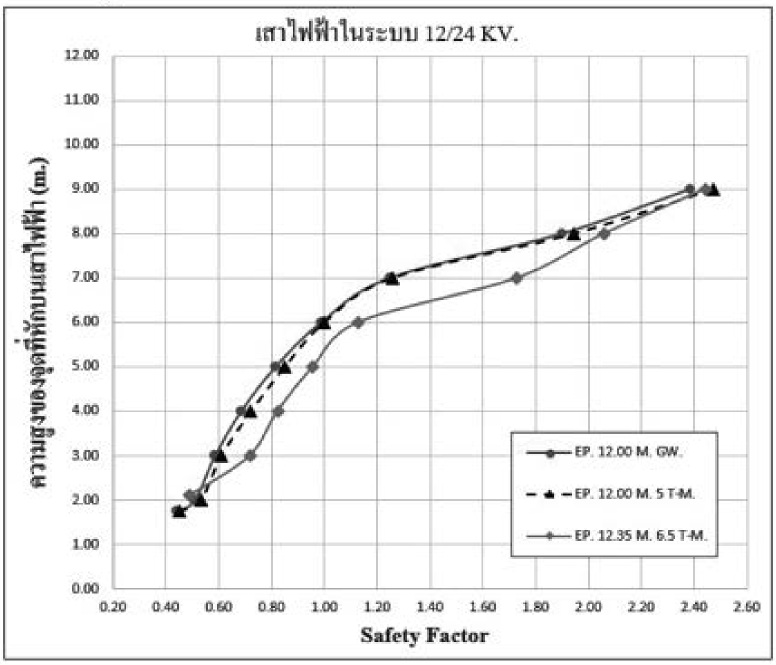

Figure 3 The height of poles versus safety factors in 12/24 KV.

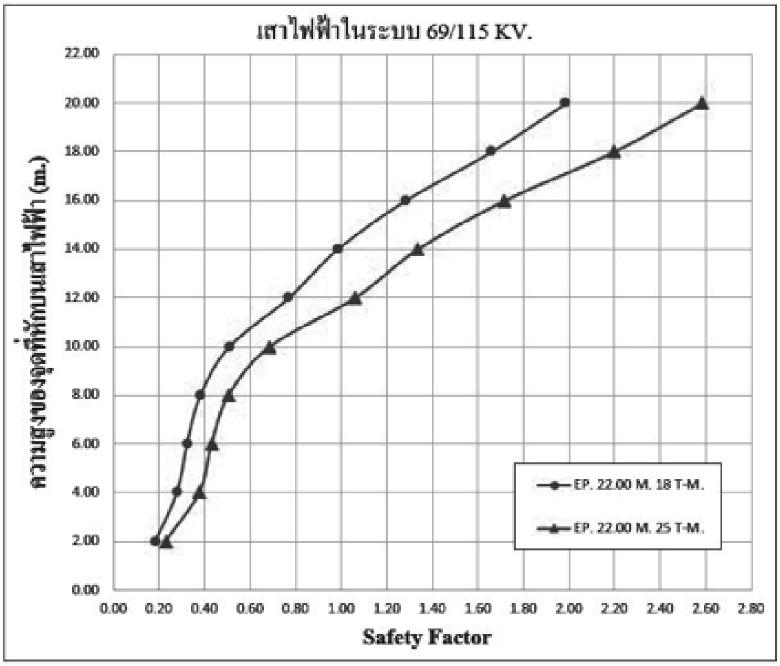

Figure 4 The height of poles versus safety factors in 69/115 KV system.

From the results obtained in figure 3 and figure 4, the optimum cracking positions for each model are concluded in table 5.

Table 5 Recommended positions to be Strengthened for utility poles.

Optimum cracking height from pole base to be strengthened (m)				
12/24 KV			69/115 KV	
12.00 m.GW	12.00 m. 5 T-m	12.35 m. 6.5 T-m	22.00 m. 18 T-m	2.00 m. 25 T-m
6.05	6.00	5.30	14.10	11.70

2.2. FEM models to strengthen the utility poles by CFRP

In this step, utility poles wrapped with plate type of CFRP were modelled according to the analytical results obtained from the previous step. The specific heights of CFRP were applied to each type of the pole systems and push over analyses were carried out. The stress analyses were calculated to compare with the strength of materials as well as to define the safety of factor values. The failure was determined by obtaining the safety of factor of concrete material along the height of pole in compressive area. The cracking of pole was judged to present when the safety factors were less than 1. On the other hand, the poles were considered to sustain the applied load when all safety values in the confined area were greater than 1. The amount numbers of wrapping to each pole were determined by the thickness values in multiply of the thickness used which is 1.2 mm. In this report, only one model of the pole in 12/24 KV system and 69/115 KV system would be expressed and discussed. For 12/24 KV system, 12.00 m GW model was selected to discuss herein in figure 5. The safety factor values calculated along the length of pole for 12.00 m. GW models when the width of 1.2 mm, 2.4 mm, 3.6 mm and 4.8 mm of CFRP were applied.

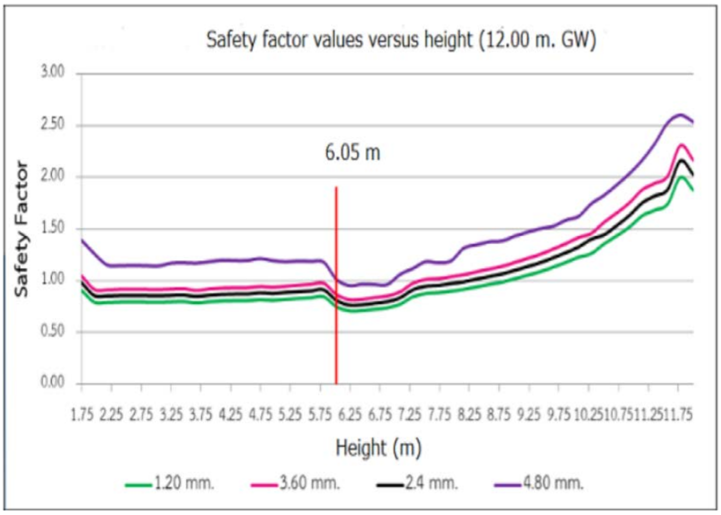

Figure 5 Safety factor values obtained along the length of pole for 12.00 m. GW model strengthen by CFRP.

It can be seen that the 4.8 mm. of CFRP thickness gives all values of safety factor greater than 1. Then, it can be concluded that to control the cracking position at 6.05 m. from the base of pole, the application of 4 wrappings of 1.2 mm. thickness of CFRP is used to fabricate.

For 69/115 KV system, 22.00 m 18 T-m model was selected to discuss and shown in figure 6. Similarly, the width of 6.0 mm, 7.2 mm and 8.4 mm of CFRP were applied to 22.00 m. model 18 T-m pole model. The 8.4 mm. of CFRP thickness gives all values of safety factor greater than 1 in the confined area beneath the height of 14.1 m. The application of 1.2 mm CFRP should be wrapped 7 times to achieve the required thickness.

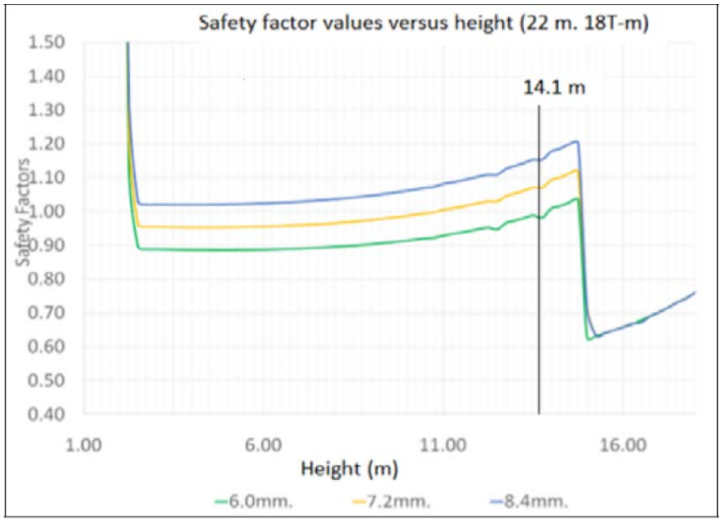

Figure 6 Safety factor values obtained along the length of pole for 22.00 m. model 18 T-m strengthen by CFRP

For the other utility poles studied in this research, the amount numbers of wrapping are concluded in table 6.

Table 6 The Amount Numbers Required for 1.2 mm. Thickness CFRP wrapping on Utility poles.

Optimum cracking height from pole base to be strengthened (m)				
12/24 KV			69/115 KV	
12.00 m.GW	12.00 m. 5 T-m	12.35 m. 6.5 T-m	22.00 m. 18 T-m	2.00 m. 25 T-m
4	4	3	7	7

2.3. FEM models to strengthen the utility poles by Steel plates

For the design criteria of utility poles in future manufacturing process, the controlling of cracking positions should be concerned to prevent progressive collapse for the toppled poles. Steel plates were introduced to strengthen the poles in this research. The material properties of steel plate had been already introduced in table 1. The sizes and weights in kg per 6 meter of chosen steel plate according to the manufacturer and are shown in table 7.

Table 7 Dimensions and weight of steel plates according to the manufacturer

Width (mm)	Thickness (mm)			
	3	4.5	6	9
12	1.7	2.5	3.4	5.1
16	2.3	3.4	4.5	6.8
19	2.7	4.0	5.4	8.1
25	3.5	5.3	7.1	10.6
38	5.4	8.1	10.7	16.1
44	6.2	9.3	12.4	18.7
50	7.1	10.6	14.1	21.2
65	9.2	13.8	18.4	27.6
75	10.6	15.9	21.2	31.8

Similar to the CFRP models, the steel plates were reinforced at the corners of the utility poles' cross sections. The specific heights of steel plate were applied to each type of the pole systems and push over analyses were carried out. The stress analyses were calculated to compare with the strength of materials as well as to define the safety of factor values. The typical cross section model is shown in figure 7 and cracking of pole is judged to present when the safety factor values is less than 1. The relationships between the height of poles versus the safety values are presented in figure 8 and figure 9 for 12.00 m. GW and 12.00 m. 5 T-m models respectively.

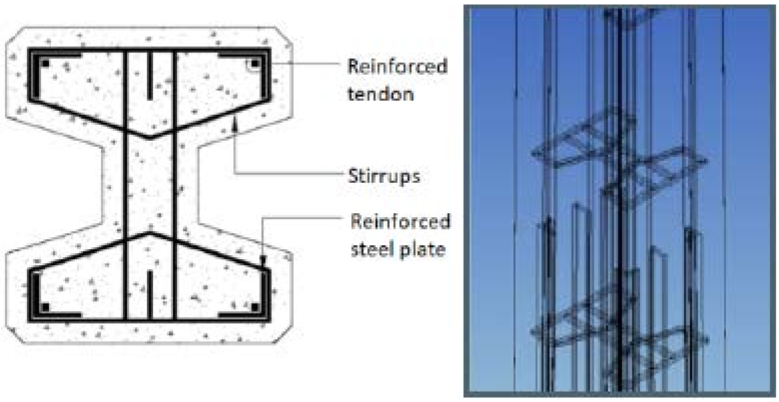

Figure 7 The typical cross section of reinforced steel plates

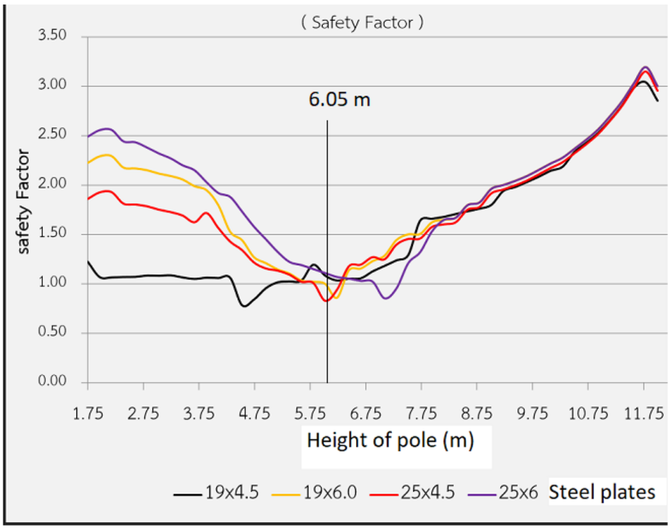

Figure 8 Safety factor values obtained along the length of pole for 12.00 m. GW model reinforced with steel plates

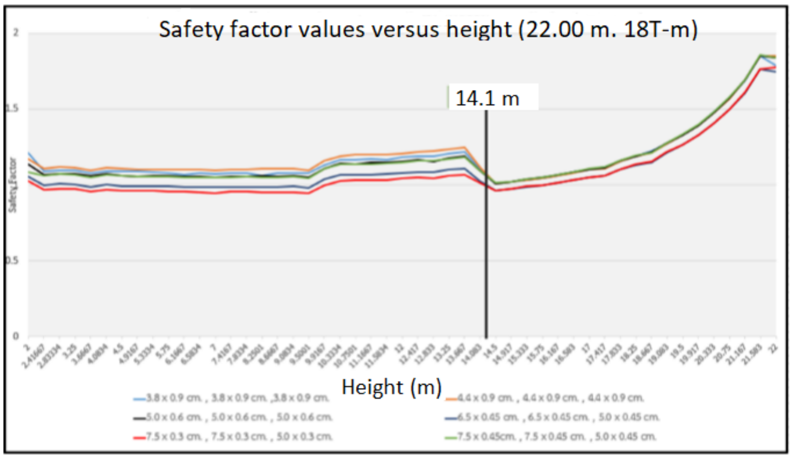

Figure 9 Safety factor values obtained along the length of pole for 22.00 m. 18 T-m model reinforced with steel plates

From these analytical results, it is indicated that for 12.00 m. GW model reinforced with the steel plate of 19x4.5 mm cannot sustain the applied push over load because the safety value less than 1 is found beneath the reinforced height of 6.05 m. It can be concluded that the least sectional area of steel plate of 25x4.5 mm or equivalent area can be applied to this type of pole to prevent the failure position until the reinforced height of 6.05 m is reached. The similar conclusion can be observed with the 22.00 m. 18 T-m model with the reinforced height is 14.1 m. The analytical results revealed that safety factor values calculated along the length of pole for 22.00 m. 18 T-m reinforced with steel plates of 65x4.5 mm and 75x3.0 mm models are lower than 1 below the reinforcement sections. In the meanwhile, the safety factor values below the reinforcement sections are higher than 1 when the application of 50x6 mm or equivalent sectional area of steel plate are reinforced. The application of 38x9.0 mm, 44x9 mm of reinforced steel plates are also found to satisfy the safety factor values for this type of pole. The conclusions of the least sectional areas of steel plates required to satisfy the safety factor values for each type of poles are summarized in table 8.

Table 8 The least sectional area of steel plates to reinforce on utility poles.

12/24 KV			69/115 KV	
12.00 m.GW	12.00 m. 5 T-m	12.35 m. 6.5 T-m	22.00 m. 18 T-m	22.00 m. 25 T-m
25×4.5	25×4.5	19×4.5	50×6	44×4.5

3. DISCUSSIONS AND CONCLUSIONS

In this study, the proposed method to prevent the specific mode of failure of utility poles had been presented and summarized. The cause of weight above the downed position of collapsed pole above the snapped point leading to produce the tensile force in electric cables was assumed to induce the continuous collapse to adjacent poles. Two strengthen methods to increase stiffness of poles were proposed to reduce the overweight of toppled portion of collapsed poles. The optimum positions of failure to reduce the weight of toppled poles were determined beforehand. The application of CFRP was employed to existing poles while the reinforcement of steel plates was proposed for the future manufacturing process. FEM analyses were utilized to define the stress ratios in order to clarify the failure criteria. The conclusions can be summarized as the followings;

- To determine the optimum cracking positions, the pushover analysis must be carried out by subjected to the pulling forces induced by the downed pole weight, the pole is judged to sustain the weight of downed portion of adjacent pole induced through pulling load in cable lines when the stress ratio is more than 1.
- For the proposed method, CFRP and steel plates can be introduced to increase the stiffness of poles in order to control the points of failure for each type of poles. Push over analysis must be carried out subjected to the cable force at the position of electric wires. The failure is determined by obtaining the safety of factor of concrete material along the height of pole in compressive area. The cracking of pole is judged to present when the safety factors is less than 1.
- In order to control the positions of failure, decreasing the stiffness of the poles is an alternative method by reducing the moment of inertia of section or sectional area, etc.

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