DEVELOPMENT OF SEISMIC CAPACITY CURVE (S.C.C.) FOR POWER DISTRIBUTION CONCRETE POLES

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ABSTRACT

Seismic assessment of power distribution network equipments is one of the most important challenges due to last seismic loss experiences.
Because of complication and variety of parameters which are effective in seismic behavior of structures and equipment, Seismic Capacity Curve (S.C.C.) development is one of the most applicable methods based on analytical and experimental studies to evaluate seismic vulnerability.
By means of S.C.C., vulnerability of each concrete pole is evaluated according to seismicity and soil bearing capacity and concrete pole capacity, simply and accurately. If the pole is not vulnerable there is no need of rehabilitation, otherwise vulnerability have to evaluate by the more accurate methods.
This paper deals with development of various S.C.C. by a finite element analysis for concrete poles which are utilized in IRAN power distribution network, with various ultimate strength grades and in different site specification.

INTRODUCTION

Failure studies of power distribution concrete pole in the past earthquakes have indicated the potential of structural damage in some of pole that related to site seismological specifications directly and soil condition. Some failure mode of concrete pole in past earthquakes has been shown in the Figures 1.
Application of Capacity curves is one the most desirable seismic assessment methods of equipment for researchers. This method is based on development of equipment seismic demand to capacity ratio due to each shaking and traced by period or parameters related by.
Seismic response parameters evaluation is one the most important steps in equipment seismic assessment and Capacity curve development, to describe different failure modes. On the other hand, seismic vulnerability depends to exceeding total equipment demands (seismic and other applicable demands) of equipment capacity.
In this paper, at first failure modes are described and simulated by finite element method, by considering seismological site specification, seismic response of concrete pole will be analyzed.

Figure.1: Bending failure (left) and significant rotation in soft soils (right) in distribution pole (Bam, 2003)

CONCRETE POLE SPECIFICATIONS

Concrete poles are categorized by length and nominal bending strength. Nominal bending strength stands for bearing load of pole in permanent service manner. (Table 1) Yield strength would be calculated as 1.5 times of nominal strength and ultimate strength for pole with nominal strength less than 400 Kgf, 3 times and for more than 400 Kgf, 2.5 times of nominal strength.[1]
The general schemas of concrete poles and rebar arrangement that are used in power distribution network of IRAN have been shown in figure 2.

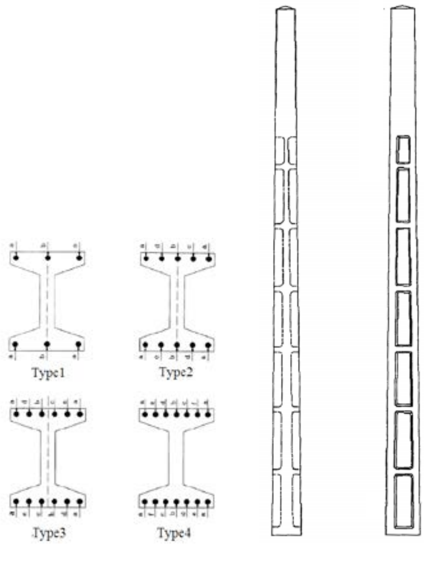

Figure.2: Concrete Poles Schemes

Table.1: Concrete Pole Specifications

Length (m)	Nominal Strength (Kgf)	Yeild Strength (Kgf)	Ultimate Strength (Kgf)	Buried Depth (m)
9	200	300	600	1.5
9	400	600	1200	1.5
9	600	900	1500	1.5
9	800	1200	2000	1.5
12	200	300	600	1.8
12	400	600	1200	1.8
12	600	900	1500	1.8
12	800	1200	2000	1.8
12	1200	1800	3000	1.8
15	400	600	1200	2.1
15	600	900	1500	2.1
15	800	1200	2000	2.1
15	1200	1800	3000	2.1

MODELING AND SIMULATION

As mentioned before, Capacity curve development needs a proper evaluation of seismic capacity and demand, and seismic demand is related to site seismological specifications directly. So, effective parameters takes into account in structural modeling to consider different situation of site such as embedment soil conditions , conductor conditions, suspension or tension type of pole. Different types of power distribution concrete poles (9, 12, 15 meters) with various strength in some soil conditions are modeled by finite element method in SAP2000 software. During simulation conductor conditions such as weight and tension of wires take into account and finally, response spectrum analysis executed based on IRANIAN CODE OF PRACTICE FOR SEISMIC RESISTANCE DESIGN OF BUILDINGS [2].

Based on results of such simulation, demand to capacity ratios for bending and shear stresses are calculated and Capacity curves are developed and categorized by soil conditions for each type of poles. In figure 2 there is sample of concrete pole modeled in SAP2000. There are main assumptions during Capacity curve development.

- All concrete poles are design based on IRANIAN guideline 374 [1] which table 1 shows specifications.
- Soil conditions are taking into account by 9 different specifications which are shown in table 2.[6]
- All poles are perfect and there are any imperfections or rehabilitations.
- Conductor specifications are as general's which are used in IRAN Power Distribution Networks.
- Maximum span length used for power distribution with 9, 12, 15 meters poles, relatively are 35, 55 and 70 meters.[1,3]
- Based on the suspension or tension pole, Capacity curves are developed.
- Ground is flat and no incline is considered. Depth of embedment is chosen based of Table 1.

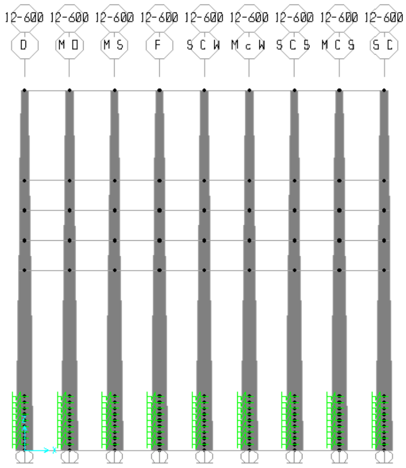

Figure.2: Finite Element Modeling of Poles in SAP2000

GUIDE LINES AND SCOPE OF ANALYSIS

Loading and design of concrete poles are based on Iranian Guide lines 374. Capacity estimation and load combination have done by American Concrete Institute (ACI 318) standards [4]. There are many standards and guide lines for soil bearing capacity, and BS EN 13899-1:2007 [5] is used for it, and embedment soil is simulated based well established references. [6,7] (Table2)

Table.2: Concrete Pole Specifications

Soil type	Soil Stiffness (Ks MN/m3)	
	Lower Bond	Upper Bond
High Dens. Gravel	220	400
Med Dens. Gravel	157	300
Low Dens. Sand	110	280
Silt	80	220
Stiff Clay	60	220
Med Clay	39	140
Saturated Stiff Clay	30	110
Saturated Med Clay	10	80
Soft Clay	2	40

CAPACITY CURVES DEVELOPMENT

During last seismic, two failure modes as the most critical ones are reported:

- Shear or bending failure at the base of pole which leads to significant inelastic deformation and at last collapse.
- Significant rotation in soft soils which leads to lateral instability.

With respect to last seismic reports, concrete pole capacity and embedment bearing capacity have to evaluate for Capacity curve development. Thus for each grades of concrete poles, seismic demand for both shear and bending stresses are calculated and respect to capacity calculated by standards, Capacity curves developed according to soil types.

Capacity curves of 9, 12, 15 meters length of concrete poles classified by suspension or tension pole, according to soil types are shown in figures 4 to 9.

CAPACITY CURVE INSTRUCTIONS

To seismic assessment of a concrete pole by the Capacity curve, 6 parameters have to determine:

1. Concrete pole specifications (capacity and length)
2. Pole position in power distribution line (tension or suspension type).
3. Importance factor (I) based on "Seismic Vulnerability evaluation of Electric Power Distribution Networks" [8].
4. Design ground motion (A) based on Iranian code of practice [2].
5. Ground seismic specification based on Iranian code of practice.
6. Determine Soil type by field investigation or an authorized reference.

Then by multiplying A in I the sign of pole capacity "AI" calculated and by soil type determination, cross of AI and soil type in curves are marked. If this mark is lower than curve according to soil type, pole are not vulnerable, otherwise seismic vulnerability have to perfume by accurate analysis. There is a sample at the end of paper for more convenience.

As shown below, pole capacity gradation due to soil stiffness gradation in tension type poles are more significant than suspension poles, which it is cause of pole position and one directional loading in tension ones. Due to high moment at the base of pole, soil behavior of embedment, is more critical and if seismic excitation causes high demand, it may tend to overturning in soft and poor soils or pole fracture in soils with high bearing strength.

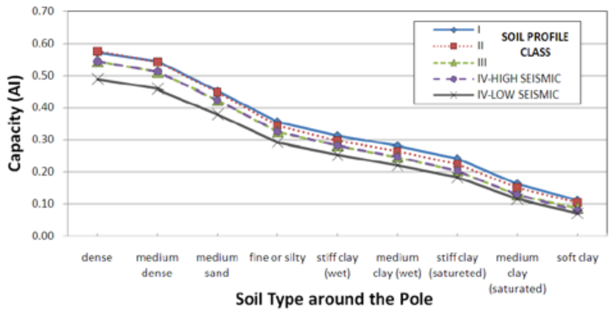

Figure.4: Capacity curve for tension pole (9 meter)

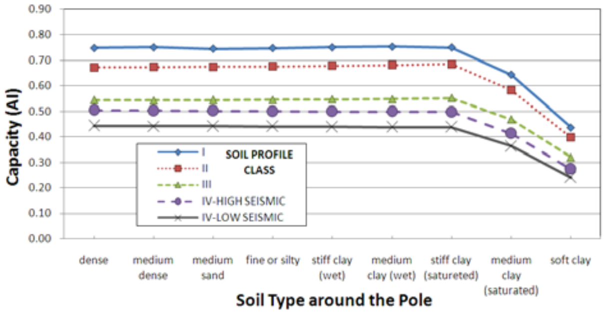

Figure.5: Capacity curve for suspension pole (9 meter)

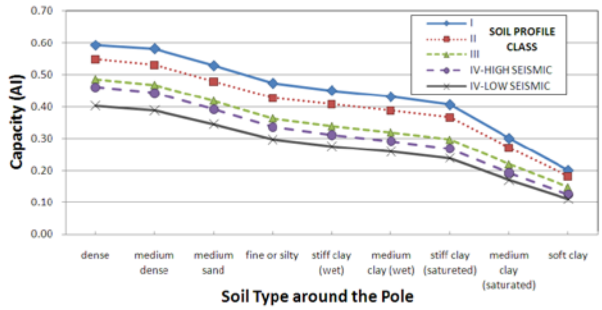

Figure.6: Capacity curve for tension pole (12 meter)

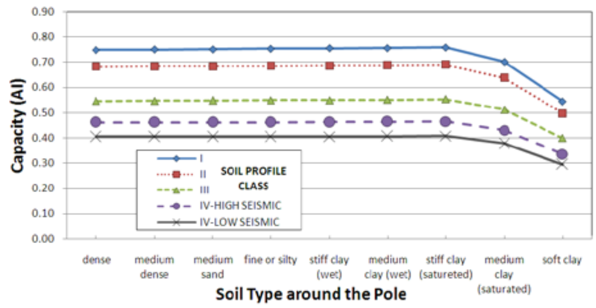

Figure.7: Capacity curve for suspension pole (12 meter)

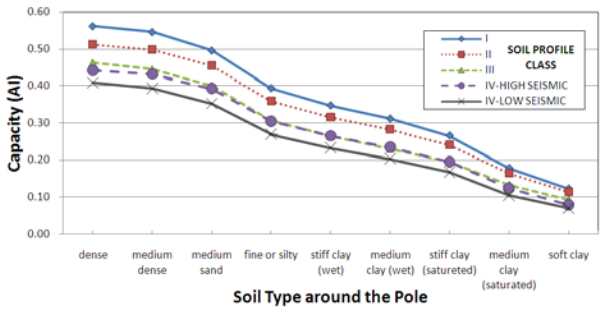

Figure.8: Capacity curve for tension pole (15 meter)

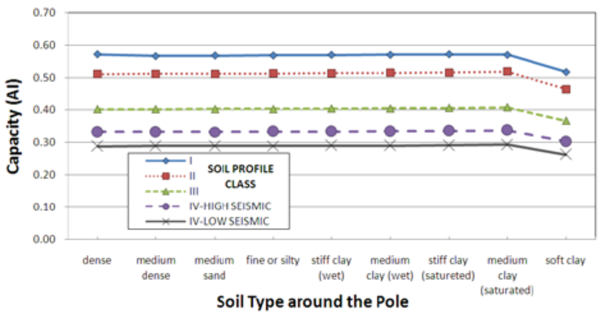

Figure.9: Capacity curve for suspension pole (15 meter)

APPLICABLE SAMPLE

- Pole specification : 12m , 800 Kgf
- Pole position in power distribution line : Tension
- Importance factor: 1.2
- Design ground motion (A): 0.35
- Ground seismic specification: Type III
- Soil type: Med Dens. Gravel

$AI = 0.35 \times 1.2 = 0.42$

As shown below (figure 10), mark is lower than the curve according to soil type III, thus the pole is not vulnerable to seismic.

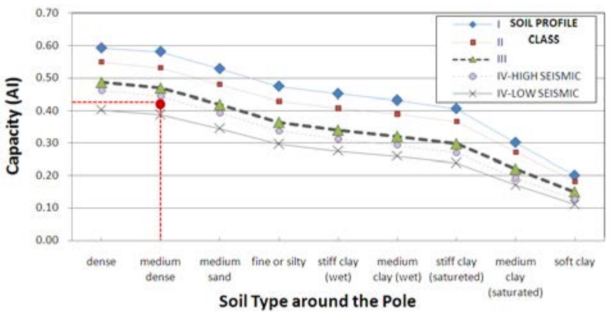

Figure.10: Capacity curve for tension pole (12 meter)

CONCLUSION

Respect to the study, these are some results mentioned below:

- Capacity curves are simple, fast, applicable tools to seismic assessment of concrete poles by seismic prone zone and importance of equipment consideration.
- Soil type variation is more effective in 12 and 15 meters length pole than 9 meters one.
- Tension type pole capacity gradation is more than suspension ones which it 'cause of one directional loading and positioning of these poles.
- Due to high moment at the base of pole, soil behavior of embedment, is more critical and if seismic excitation causes high demand, it may tend to overturning in soft and poor soils or pole fracture in soils with high bearing strength.

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