Seismic Fragility Evaluation of Power Line Using Incremental Dynamic Analysis Method

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Abstract. High Voltage Transmission Tower is an important for distributing electrical energy in a large network. It is one of essential infrastructure in the modern life and should be maintained in high performance. In the event of earthquake, however, this structure may be damaged. This paper aims to evaluate seismic risk of this transmission tower by means of its fragility. An existing tower of 230 kV with 49 m height was 3D modeled in computer with software seismostruct. An incremental dynamic analysis was employed to obtain the structure dynamic performance by using finite element package. Selected ground motion records were matched with and scaled to the target response spectra. Three damage point, namely serviceability (SA), Damage Control (DC) and Collapse Prevention (CP) were then used to state the damage threshold. The fragility function as conditional probability that certain damage state is exceeded given a level of ground motion intensity was the developed for the powerline tower. Expressed as a fragility curve, the function relates earthquake intensities with the probability of exceeding certain limit states. This curve will provide rational basis for evaluating the seismic risk of the infrastructure.

Keywords: High Voltage Transmission Tower · Fragility · Seismic risk

1 Introduction

High Voltage Transmission Tower (SUTT) is one of media transmission electrical often used for anything. At the time, electrical energy is one of the most important components to advance economic global. With the development of the times in Indonesia especially in the technology filed, requirement for electric power is a must to increase reliability. Besides of that, SUTT as important role in terms of providing electricity sources and local distribution as well as interlocal distribution so it needs to be improved the worthiness from earthquake resistant. Considering the importance of the SUTT structure for human of life so, to do analyse how hard tower by knowing the possibility of damage structure by seismic fragility assessment.

Fragility curve is a measure seismic performance of the probability fragility structural due to an earthquake and the structural system by itself. Fragility curve can be

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obtained by various method, one of which is incremental dynamic analysis method. Incremental dynamic analysis is a numerical analysis method that requires non-linear time history responses from previous ground motion. The response is scaled to determine the magnitude of the response of the analyse structure [3].

There have been previous studies that discussed steel structures with various concentrations of knowledge including Li et al. [5] conducted an analysis related to the probability of earthquake damage and the fragility curve experiencing ground motion in the field area which was developed with linear and bilinear models using ABAQUS software stating that the fragility curve with a more accurate and reasonable biliner model, in 2015 [8] analyzed the fragility and collapse estimates for transmission towers effect wind and rain loads, which concluded that rain loads contributed greatly to the collapse of the towers. Meanwhile there are also research [10] who have investigated the average frequency function of the collapse of steel frame television towers due to earthquake loads with the incremental dynamic analysis method using the SAP2000 program stating that the direction of earthquake action greatly affects tower capacity and the fragility function can be approached with a lognormal distribution. From several previous studies, there has been no research related to the analysis of sutt structures with incremental dynamic methods using the Seismostruct program. So, author took this title to develop previous research although with a different model of existing structure. The purpose of this study is to evaluate the probability of collapse of SUTT subjected to earthquake loads with a certain intensity. The probability of collapse of the SUTT structure is described by the fragility curve of the relationship between probability and maximum ground acceleration during an earthquake which is commonly called Peak Ground Acceleration (PGA).

2 Research Methods

2.1 Secondary Information

In this research, it will analyze the existing structure of the 230 kV High Voltage Air Line located on the Pekanbaru-Dumai Toll Road in Duri, Pekanbaru, Indonesia with a height of up to 52.1 m at coordinates 1.259619 LS and 101.213097 BT. Where the SUTT structure on toll road sections is built for lighting needs on toll road sections. The structure uses steel material. Additional loads modeled on this structure are AS70 ground cable load, 2xACSR 250 conductor cable load, wind load and incremental load from the seismic record. Based on the data in the field, Duri location belongs to the category of soft soil site class (SE). Based on the spectral value of acceleration from the puskim spectra design shown in Fig. 1 period 0 s–4 s for the Duri region, the PGA value = 0.185 g, Ss = 0.37 g and S1 = 0.256 g.

2.2 Modelling Parameter

The software used for modelling and incremental dynamic analysis is using Seismostruct. The conversion of ground motion recording accelorogram data into a spectrum response

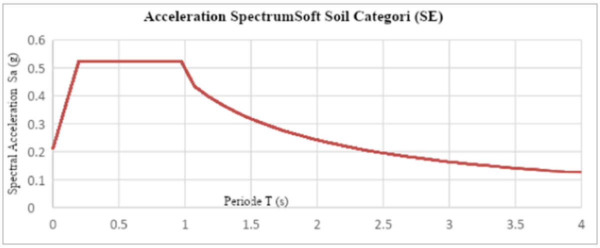

Fig. 1. Spectrum Target Responses

Fig. 2. Modelling Transmission Tower

requires the help of Seismosignal software. In addition, for matching spectral acceleration from the spectra response ground motion records and spectral acceleration from the spectra response target using Seismomatch.

The structure used to steel material with various frame types, that are: HL-100x8, HL-110 x 8, HL-120x10, HL-130x10, HL-40x4, HL-130x0, HL-90x6, HL-40x4, HL-50x4, HL-60x5, HL65x5, HL-70x5, HL75x5, HL-75x6, HL-80x6, HL-90x5, HL-90x7, L-40x4, L45x4, L-50x4, L-50x5, L-60x5, L-65x5, L-70x5, L-75x6, L-80x6, L-90x7, L-90x6, L-55x4, PL-40x5. H profiles are used on sutt support main rods, L profiles are used on SUTT bracing parts, and the PL profile at the top of the bracing. The structural design presented in this study is a steel structure consisting of a class of elements. The defined element class is then used to combine between nodes to form an element model resembling the existing structure or structure to be planned. Figure 2 shows sutt modeling that combines several nodes to form an element resembling an existing image.

2.3 Analyse Method

The analysis is carried out using the incremental dynamic analysis method, which is a time history analysis that is scaled repeatedly with several previous seismic records in order to get the actual behavior or structural response if there is an earthquake in the future. In accordance with SNI Earthquake 1726: 2019 states that at least 5 historical recordings of the time of acceleration of ground motion must be selected from several

Table 1. Ground Motion Records

Number	Earthquake Name	Year	Station Name	Earthquake Magnitude
1	San Fernando	1971	LA - Hollywood Stor FF	6,61
2	Imperial Valley	1979	"El Centro Array #1"	6,53
3	Northridge	1994	Garden Grove - Santa Rita	6,69
4	Kobe - Japan	1995	Kakogawa	6,9
5	Loma Prieta	1989	Gilroy Array #7	6,93
6	Irpinia, Italy	1980	Brienza	6,9
7	Superstition Hills	1987	Parachute Test Site	6,54
8	San Francisco	1944	Golden Gate Park	5,28
9	Northwest China-03	1997	Jiashi	6,1
10	Kern County	1952	Taft Lincoln School	7,36

earthquake events to determine the behavior of the structure when it receives the actual earthquake load.

The ASCE7 standard explains that the selection of ground motion records is based on earthquake magnitude, distance and soil conditions. However, the main thing that is needed in choosing an earthquake record is to have a similarity in the form of the spectra response to the shape of the spectra response target. So that this study used 10 ground motion records listed in Table 1. These seismic recordings are selected from the ground movements recommended by (FEMA) and the detailed acceleration information respectively. Seismic records were obtained from the Pacific Earthquake Engineering Research Center (PEER, http://peer.berkeley.edu/).

3 Result and Discussion

3.1 Eigen Value Analysis

After all the modeling steps have been completed input, the next step there is eigenvalue analysis can automatically calculate the specific gravity of the SUTT structure. Table 2 shows the results of the natural vibrating period of a structure itself. Eigen results consisting of a natural vibrating mode and a natural vibrating period are used for the earthquake spectrum matching process. The results of the eigen analysis used for the matching process are the first vibrating period in Table 1, which is 0.462. Where the result of the first vibrating period will be multiplied by the lower threshold (0.2T) and the upper threshold (1.5T).

3.2 Scaling and Matching

Data from the PEER Ground Motion Record has a spectrum response that is different from the design spectrum response, so the researchers scaled between the Sa value from

Table 2. Vibrating Period Structure SUTT

Mode	Period
1	0.46202023
2	0.45236095
3	0.22669714
4	0.18971232
5	0.17785414
6	0.14928108
7	0.14872622
8	0.13398445
9	0.12806968
10	0.12391309

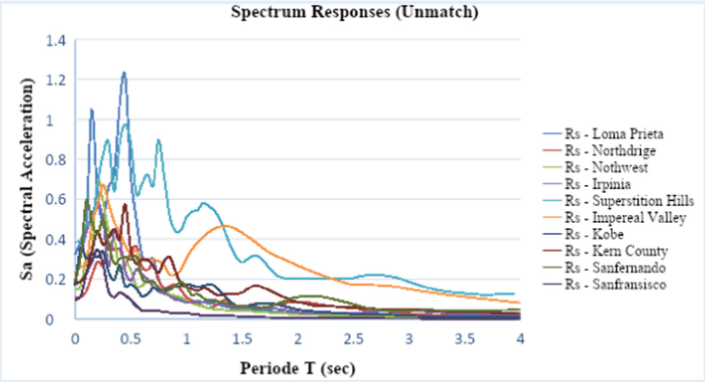

Fig. 3. One Set Spectra Response (unmatch)

the ground motion records spectral response and Sa from the target response spectra. The spectral acceleration value used to calculate the scale factor is a range of 0.2T to 1.5T where T is the first vibrating period of the eigene result of the structure itself, namely T = 0.462 s and the range of values used is 0.2T = 0.092 s and 1.5T = 0.693 s. Furthermore, the scale factor that has been calculated can be used to match between Sa from the ground motion records spectra response and Sa from the spectra response target so that the two data are matched. The graph in Fig. 3 shows the spectrum response before matching with the target spectrum response, where the shape of the graph still matches the results of PEER Ground Motion Records. Meanwhile, Fig. 4 shows the response spectrum after matching with the response spectrum of the target using the Seismomatch program, it can be seen that the shape of the graph resembles the target response spectra design.

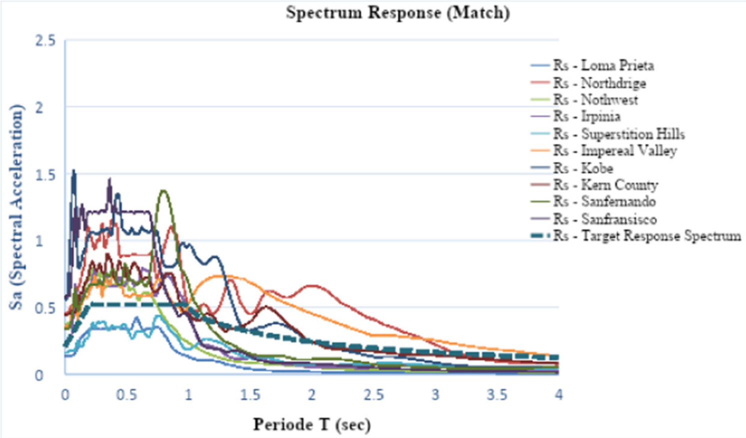

Fig. 4. One Set Spectra Response (match)

3.3 IDA Curve

Incremental Dynamic Analysis outputs are in the form of acceleration, velocity and displacement. The response used in this study was displacement. In previous studies, extensive research efforts have been made to select the optimal intensity measure (IM) and damage measure (DM) for fragility analysis. Commonly used IMs are peak ground acceleration (PGA), spectral velocity (Sv), and spectral acceleration (Sa) in the base period, etc. Among the relevant intensity measures used for this study is PGA in units of gravity (g). This is because the PGA is quite practical in increment results and can be multiplied by the earthquake intensity scale directly at the time of running the IDA. Meanwhile, the DM used in this study is the inter-segment displacement ratio (ISDR). ISDR was chosen because structural shifts between segments showed a better correlation with the degree of structural damage.

Every earthquake that is input from several seismic records already matching will give displacement results on each node. So that one earthquake can be made one IDA curve. In the study presented, Fig. 5 shows 10 seismic records so that it will produce 10 graphs of the IDA curve.

3.4 Limit State

Determination of the limit of structural damage in this study will be explained based on the Li, Tian, etc. method (2019). This method used to displacement reach value for limit states. The first state limit, called “serviceability” (“SA”), is defined as the limit at which a tower can continue to work with little or no repair after an earthquake. The appropriate threshold is taken to be 0.8% which is the end point of the elastic stage. The second limit that is “damage control” (DC) is the intermediate level between survivability and collapse prevention. This condition that ower had suffered significant damage, but could still support its own weight. However, there is no clear method for determining the threshold for this boundary state. In this study, the threshold for damage control of

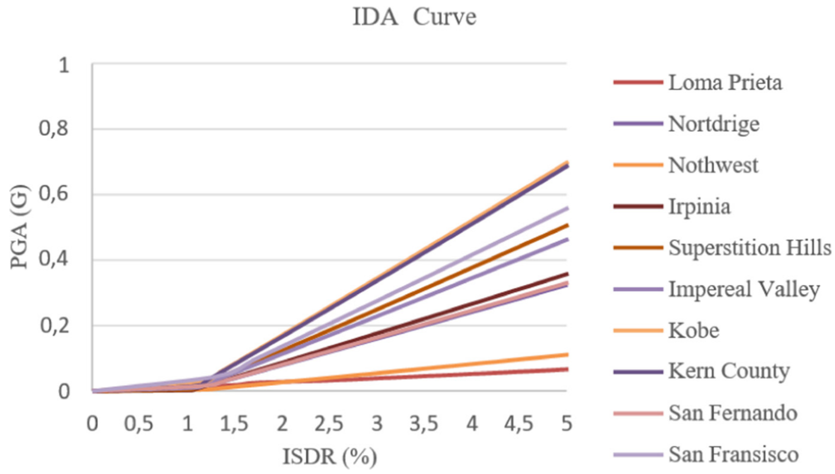

Fig. 5. IDA Curve

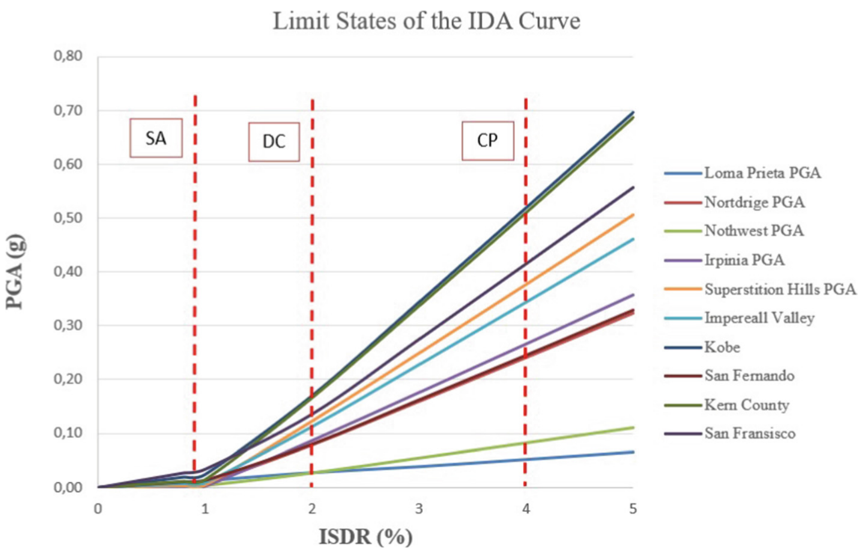

Fig. 6. Limit States IDA Curve

transmission towers was taken as 2%, the recommended value for steel frames. The third limit, namely "collapse prevention" (CP), is that the tower can no longer support its own weight and begins to collapse. Pushover curve, this boundary state corresponds to the point where a small increase in lateral force (Fig. 6).

3.5 Fragility Curve

The seismic fragility curve is a probability of the degree of fragility of a structure. It is because of its nature that various standard deviations of uncertainty (β) appear. Standard deviation is a supporting parameter for estimating the level of fragility of the structure due to the acceleration of the soil and the value of its uncertainty of capacity. The fragility curve can be formed after all the standard deviation values have been calculated. Calculating the standard deviation there are several variables including the standard deviation of the uncertainty of the structural capacity (βc), the standard deviation

Table 3. Calculation of Standard Deviation

Earthquake Name	**PGA (g) Limit State SA**	**PGA (g) Limit State DC**	**PGA (g) Limit State CP**
San Fernando	0,010	0,028	0,052
Imperial Valley	0,007	0,079	0,241
Northridge	0,003	0,027	0,083
Kobe - Japan	0,002	0,087	0,357
Loma Prieta	0,004	0,123	0,376
Irpinia, Italy	0,007	0,113	0,345
Superstition Hills	0,020	0,170	0,520
San Francisco	0,012	0,166	0,510
Northwest China-03	0,011	0,081	0,246
Kern County	0,027	0,136	0,416
Jumlah	0,10	1,01	3,15
n	10,00	10,00	10,00
Mean (μ)	0,01	0,10	0,31
Standard Dev (σ)	0,01	0,05	0,16
v	0,75	0,50	0,51
θ	0,01	0,09	0,28
Jumlah	0,10	1,01	3,15
β M(ds)	0,80	0,80	0,80
β c	0,67	0,47	0,48
β d	0,45	0,45	0,45
β (ds)	0,85	0,83	0,83
β M(ds)	0,80	0,80	0,80
β c	0,67	0,47	0,48
β d	0,45	0,45	0,45
β (ds)	0,85	0,83	0,83

of the uncertainty of the value of the limit of the damage condition (βm (ds)), the standard deviation of the uncertainty of the demand spectrum (βd) and the standard deviation of the total uncertainty (βds). The total deviation can be calculated using Eq. 1. The results of the calculation of standard deviations with three limits of structural damage are shown in Table 3.

$$\beta_{ds} = \sqrt{](\mathrm{CONV}[[\beta c, \beta d])^2 (\beta_{M,ds})^2} \quad (1)$$

The standard deviation results in the table can be used to calculate probabilities. In this study, the probability of structural damage using an Eq. 2 from Keith Porter, 2016. The calculation of the probability that will form the fragility curve is carried out repeatedly ranging from a PGA value of 0 g to 6 g. Here at Eq. 2 is one example of how to calculate the probability at the SA damage limit with a value of Φ of 0.1.

$$P(S_d) = \Phi \frac{\left(\ln \ln \left(\frac{x}{\theta}\right)\right)}{\beta_{(ds)}} \quad (2)$$

$$P(S_d) = \Phi \frac{\left(\ln \ln \left(\frac{0,01}{0,2}\right)\right)}{0,85}$$

$$P(S_d) = 3,74$$

with:

Φ: lognormal standard cumulative distribution function

Summary of probability calculations plotted into curves along with PGA distribution functions such as which is illustrated in the curve of Fig. 7. Each graph shows the probability of damage to the structure at a certain limit. Where the green color graph

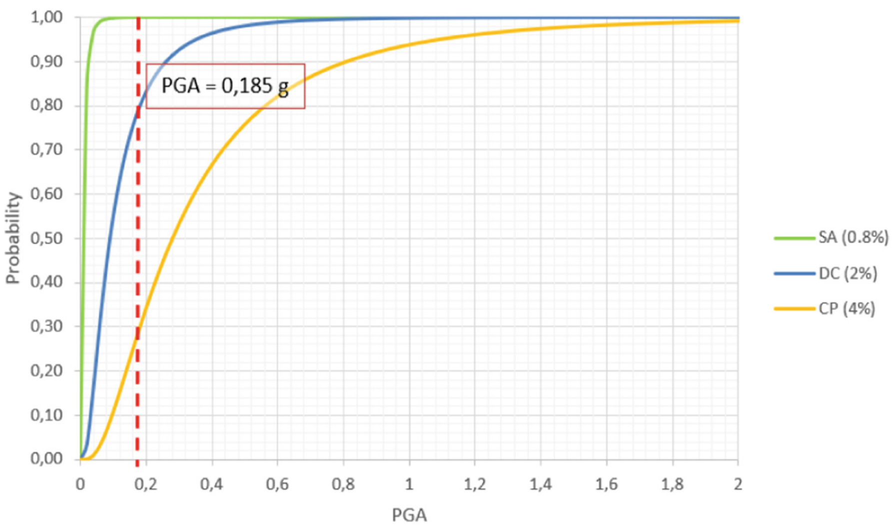

Fig. 7. Fragility Curve

shows the probability of damage at the severability limit (SA), the blue color graph the probability of damage limit at the damage control (DC), and the yellow color graph the probability of damage limit at the collapse prevention (CP).

4 Conclusion

Based on the results of the analysis that went through various research stages it can be evaluated that the IDA curve Fig. 5 that is formed has almost the same graph, although the earthquakes load are differently. The IDA curve shows a relatively linear structural behavior at the beginning and then hardening or strengthening. Hardening indicates an increase in the stiffness of a structure. When hardening occurs, the response of the structure which initially coincides becomes separated, which shows differences in the response due to earthquake loads by a structure.

According to the data already mentioned, the SUTT structure located in Duri, Pekanbaru with a PGA value of 0.185 g has a probability of damage according to the fragility limit which can be seen in Fig. 7, that are the serviceability value of 100%, damage control of 78% and collapse prevention of 27%. It is very clear that in the SA limit conditions the tower can still stand firm without any indication of repair. So the researchers argue that the material used in this study is very strong. This evaluation describes the probability of damage to a certain extent and can be used as a reference to develop the reliability of the SUTT.

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