Geotechnical Assessment for Truss Bridge using Fuzzy-based Soft Computing: Case Study - Kedaung Bridge, Tangerang, Banten Indonesia

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Abstract: Kedaung Bridge is a truss bridge that connect two sub-districts in Tangerang. This bridge pass over Cisadane River. Although the bridge is newly opened, any hazard may be occurred during operating periods. Substructure of bridge itself is prone to hazards such as ground displacement, slope instability and seismic-related hazard. Typical traffic data and soil investigation data will be used to analyze ground displacement and slope instability where the bridge located. Local geological and seismic data will be used to assess seismic-related hazard. A risk assessment for substructure shall be conducted. Fuzzy Analytical Hierarchy Process (FAHP) will be used to analyses various geotechnical aspects. Hazard identification, risk rating, risk analysis, and risk assessment are steps conducted in FAHP method. The ranking model can be used for quick sensitivity assessment of the effect of various site condition. Classification and rating of risk can be done with proposed method. Classification of risk will be based on soil type and geological condition. This assessment can be a tool or recommendation for local government where the bridge located. Priority list will be created using this method and enable decision makers to decide on either carrying out further detailed evaluation or consider any other actions for the bridge.

1 INTRODUCTION

In a road network system, bridges play an important role as a complementary road infrastructure. Bridges can be the backbone of infrastructure that links one region to another (Andric & Lu, 2015). Bridges can connect road that is separated by rivers, lakes, ravines, valleys, straits, highways and railways. In its development, the bridge undergoes the evolution from wooden and simple stone bridges to bridges with more complex structural systems and advanced materials. The advanced materials used in more complex bridge structure (such as concrete, steel and cables) that continue to develop will encourage the construction of bridges with more complex technology than ever before.

In Indonesia, Directorate General of Highways of Ministry of Public Works and Housing (*Dirjen Bina Marga Kementerian PU-PERA*) is responsible for bridge management through archipelago. The Directorate General of Highways uses the Bridge Management System (BMS) for more systematic monitoring and planning of the bridge. The BMS developed and owned by the Directorate General of Highways serves as a tool for the process of storing bridge-related data; such as design work, construction, rehabilitation and monitoring of bridge condition. For the purposes of the bridge survey, Indonesia's Directorate General of Highways has a Working Unit of Planning and Supervision of National Roads and located in each province.

According to data collected from the Ministry of Public Works and Housing Statistics Information Book (*Buku Informasi Statistik Kementerian PUPERA*) year 2015, the total number of bridges in Indonesia recorded by the Ministry per year 2014 are 14710 bridges with various conditions. The details of the bridge conditions recorded are 6609 bridges (45%) in good condition, 3137 bridges (21.3%) with medium condition, 3253 bridges (22.1%) at lighty-damaged condition, 1360 bridges (9.2%) in heavily-damaged condition, 314 bridges (2.1%) with critical condition and 37 bridges (0.3%) already collapse / break-up.

From the data above, the condition of the bridge in Indonesia is composed of various conditions,

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ranging from good conditions until the condition of collapsed or broke. The bridges listed above are bridges that have been designed and built by the Directorate General of Highways. Those bridges have various shaping materials with varying length and spans.

Kedaung Bridge is considered as newly built bridge by local government of Tangerang that connect two sub-district in Tangerang. It crosses Cisadane River. The bridge consists of two main lane and can handle until mid-size truck. Local government is the entity that hold responsibility for Kedaung Bridge (under supervision of Indonesia Directorate General of Highways of Ministry of Public Works and Housing).

Assessment process of Kedaung Bridgge is to determine the current state of the bridge can be done by collecting various related data and then those data can be analyzed and generate a value that will be able to assist in the decision-making process. Related research on the structure of the bridge (such as deck, frame and bridge pier or pier) has relatively much research on it. Research on the assessment of the sub-structure of bridge is not as much as upper-structure of bridges. Damage to upper and lower structures of jembaatan will result in disruption of the service life of the bridge.

2 EVALUATION AND ANALYSIS

To evaluate sub-structure condition of a bridges, several methods can be conducted. Then, after evaluation process, assessment process shall be done. In this paper, assessment process is done by Fuzzy Analytical Hierarchy Process (Fuzzy AHP). Fuzy AHP is based on fuzzy set that is developed by Lotfi Zadeh in 1965. The result of Fuzzy AHP is rating of each criterion. Rating that is respected to value of each criteria is the result of assessment process. Based on the rating, decision making can be done with those rating.

In this paper, evaluation criteria will be described based on text book. Slope stability, seismic hazard analysis, liquefaction study and Fuzzy AHP will be described in the following subsection.

2.1 Soil Parameter Interpretation

According to Duncan and Wright (2005), the process of slope stability evaluation needs to be done to determine the safety factor of a slope. Clear and comprehensive evaluation results should also be done for the following reasons:

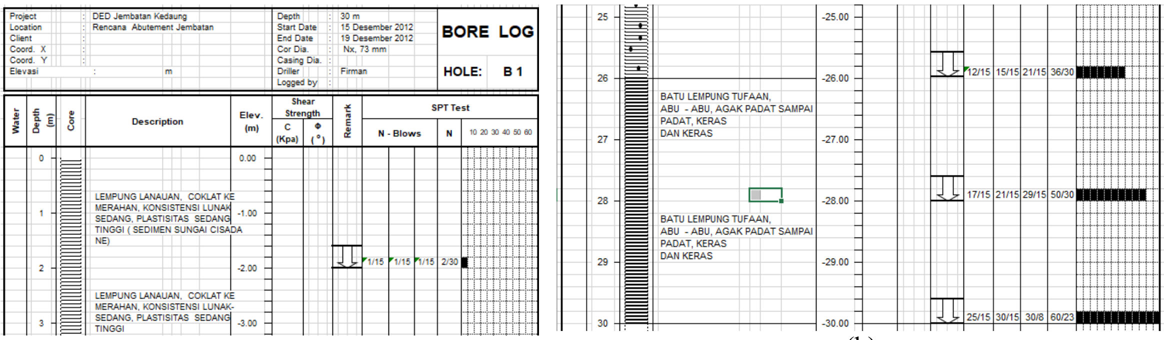
- Evaluation results should be checked by a few engineers and experts from relevant institutions. Multiple examinations are intended to minimize errors that may occur during the evaluation process and to gain a different perspective on a problem.
- Evaluation results must be clear and understandable by the client
- Responsibility for engineering evaluation results is usually given to engineers at an institution or company. The engineer must understand the results of the evaluation and understand the basis of the decisions taken in the analysis and evaluation.
- Evaluation results should be well documented. Good documentation will make it easier if the data at any time required in the future.

It is inevitable that each slope location evaluated has different characteristics from one another. In Java, soil conditions in each province will be different. Geological detail plays an important role in slope stability, and for that, geological information of a region is very important (Duncan & Wright, 2005). Then, the next step in the evaluation of the stability of the slope is the evolution of the soil property. Evaluation of soil properties will be closely related to geotechnical investigations. Geotechnical investigation work will include field and laboratory work. The properties obtained are quite diverse, among others are: property of soil shear strength, soil stiffness, soil physical characteristics and others. In slope stability, shear strength parameters and soil density are prioritized.

Soil investigation work has been conducted at project site of Kedaung Bridge. Soil investigation works consist of field work (boring) and laboratory work. Boring work has been conducted in 2 points of reference. One point is located in one side of approach section and the other is located in another side of approach section. Boring work is done until 30 meters depth. Boring log report and soil mechanic summary report are shown in Figures 1 – 3.

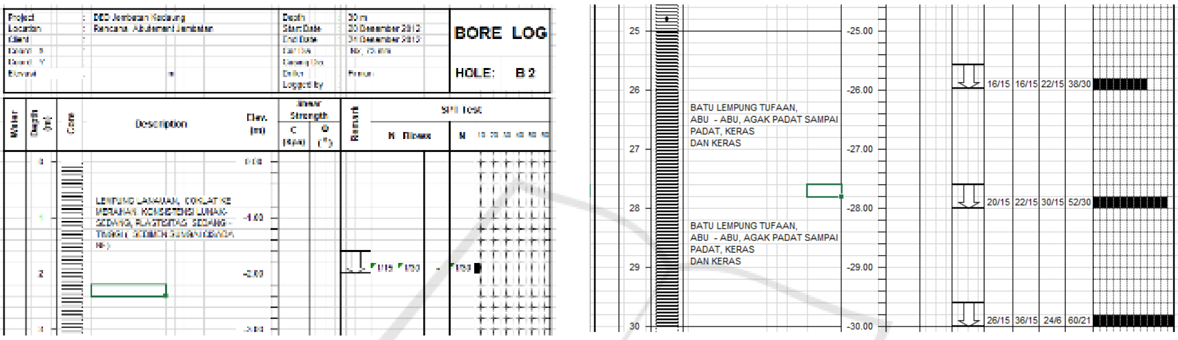
Upper section of soil is dominated by clay until 25 to 26 meter depth and after that section, tuff / cemented clay mixed with rock is dominated. Borehole 1 and bor-hole 2 is done at minimum required depth (30 meter).

At least one undisturbed sample (UDS) in each borehole are taken for laboratory work. Several testing have been conducted in laboratory work. Atterberg limit test, consolidation test, soil density test, grainsize distribution test, water content test and triaxial test are testing item treated for each UDS.



(a) (b)

Figure 1: (a) Upper section of boring log B1 report, (b) Lower section of boring log B1 report.



(a) (b)

Figure 2: (a) Upper section of boring log B2 report, (b) Lower section of boring log B2 report.

PROJECT : SOIL TEST

LOCATION : Jembatan Kedaung

SUMMARY OF SOIL MECHANIC LABORATORY TEST

No	LOCATION STA	BORE HOLE	DEPTH (meter)	CLASSIFICATION USCS	Wn (%)	γm (gr/cm³)	γd (gr/cm³)	Void Ratio e	Porosity n	Sr (%)	Specific Gravity Gs	WL (%)	WP (%)	IP (%)	GRAVEL (%)	SAND (%)	SILT (%)	CLAY (%)	% finer by weight passing no. 200 sieve	Triaxial UU Total Stress φ Degree	Triaxial UU Total Stress c kg/cm²	Consolidation Test Cc	Consolidation Test Cv cm²/sec
1	Kedaung Barat	B.01	4.50 - 5.00	MH	52.934	1.506	0.985	1.680	0.612	85.106	2.540	72.25	40.44	31.810	0.00	33.09	37.78	29.13	66.91	5.185	0.061	0.327	2.39E-03
2	Kedaung Barat	B.02	4.00 - 4.50	MH	57.816	1.517	0.962	1.696	0.616	90.426	2.496	101.09	43.68	57.410	0.00	5.20	52.28	42.52	94.80	4.450	0.060	0.323	2.21E-03

Figure 3: Summary of soil mechanic laboratory test for whole bor-hole.

2.2 Slope Stability Evaluation

Basically, calculation or analysis of slope stability can be done manually or using geotechnical software. Manual computations are calculated using several methods such as Bishop, Taylor, Spencer, Fellenius, Morganstern and other methods. The whole method of manual calculation is based on the concept of equilibrium limit. Then, if using the software, the geotechnical software widely used and will be used in this research is Plaxis and Geoslope. The concept of calculation on Plaxis is based on the finite element method (FEM), while the concept of calculation on Geoslope is based on the concept of equilibrium limit.

In this case, soil stability is conducted using Geoslope software. Input data for Geoslope are consist of geometry of slope analyzed, soil property data. loading data at the top of slope (bridge self weight and traffic load) and environmental data (such as seismic load).

Three main analysis in Geoslope for this case are long-term, short-term and seismic condition. Long-term condition is conducted and deal with daily load such as traffic load in normal condition. Short-term

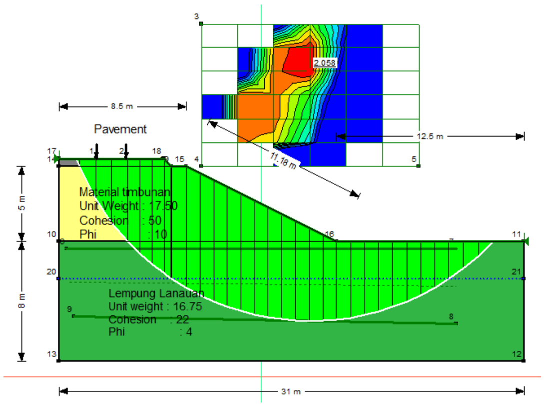


Figure 4: Geoslope output for long-term condition in bor-hole 1 location, critical SF = 2.058.

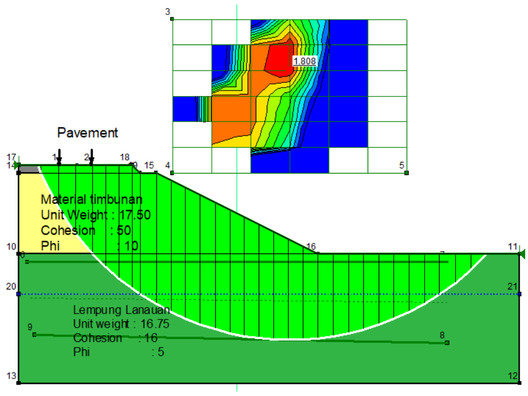


Figure 5: Geoslope output for short-term condition in bor-hole 1 location, critical SF = 1.808.

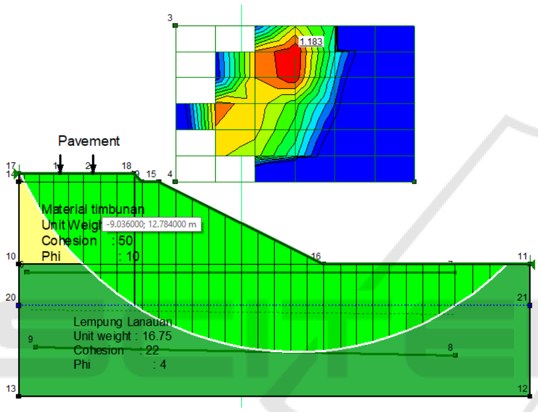


Figure 6: Geoslope output for seismic condition in bor-hole 1 location, critical SF = 1.183.

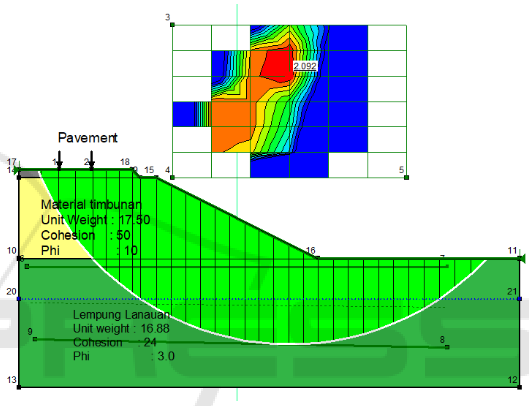


Figure 7: Geoslope output for long-term condition in bor-hole 2 location, critical SF = 2.092.

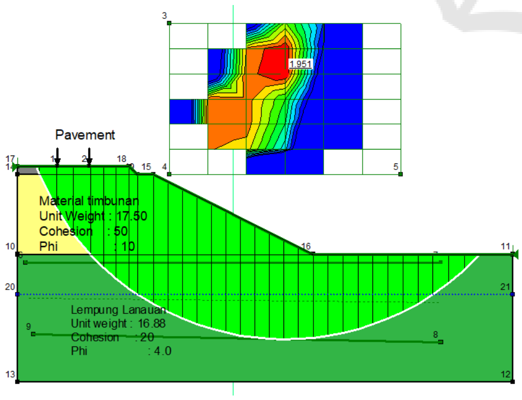


Figure 8: Geoslope output for short-term condition in bor-hole 2 location, critical SF = 1.951.

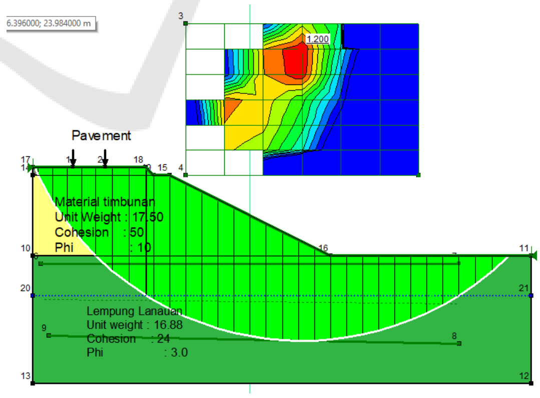


Figure 9: Geoslope output for seismic condition in bor-hole 1 location, critical SF = 1.200

condition is deal with short and considerably quick load when traffic jam and big vehicle get jammed and stroked for one time at both lane along the bridge. While, seismic condition is deal with seismic load. In the lifetime of bridge, the bridge itself can be faced with earthquake, thus, the slope under abutment of bridge has to be analyzed in seismic condition as well.

Figure 10: GoogleEarth™ imaginary with red circle in 500 km radius.

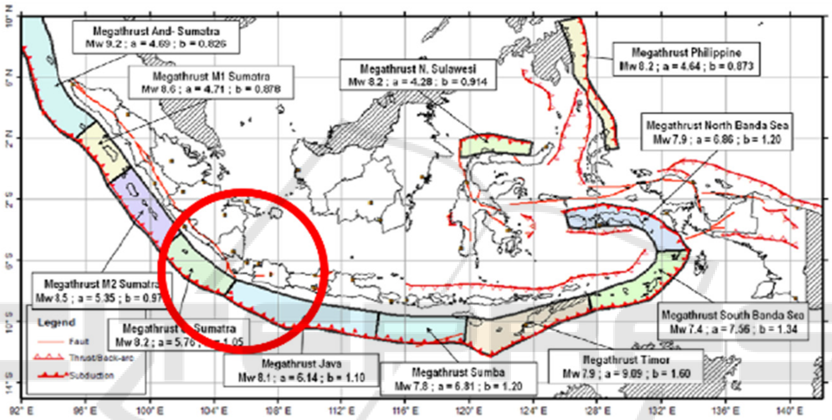


Figure 11: Maximum magnitude from subduction or megathrust seismic source (*Study Report Summary of Indonesia's Seismic Map Revision Team, 2010*).

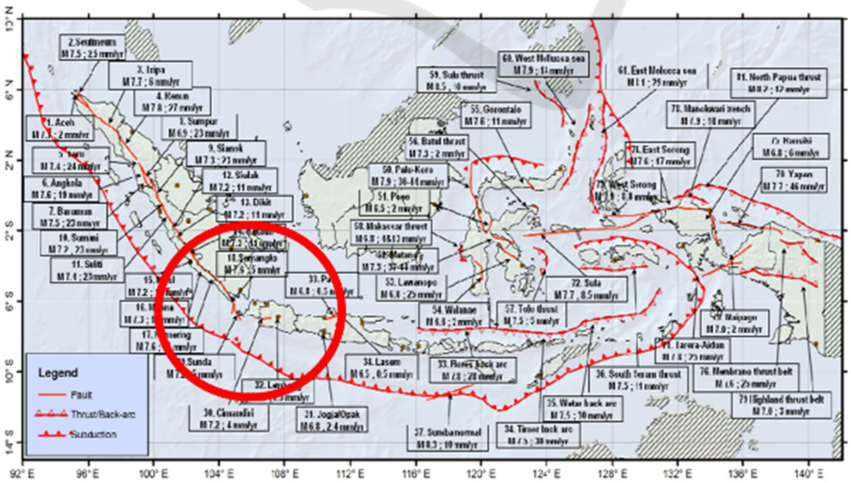


Figure 12: Maximum magnitudo and slip rate from fault seismic source (*Study Report Summary of Indonesia's Seismic Map Revision Team, 2010*).

The output for slope stability analysis in Geoslope is safety factor (SF) value. Safety factor value is reflected the condition of the slope. Based on SNI 8460-2017 (*Geotechnical Design Guidelines*), several value of safety factor has been considered for every uncertainty. Conservative design of slope is one main focus in SNI 8460-2017. After all required data has been input in Geoslope, the software will analyse the data and safety factor value will be clearly visible for several condition. The geoslope outputs are shown in Figures 4 – 9.

2.3 Seismic Hazard Identification

Tangerang is located in Java Island and this area is surrounded by several active and unstable tectonic plates. The southern plates is part of ring of fire. Radius taken for seismic hazard identification is 500 km. Seismic source can be located and identified inside the circle.

Detailed area information are as follow, it was located at Tangerang, Banten, Indonesia with the coordinate of E. 678 541.88 (use UTM coordinates system), N. 9 322 379.92, Zone: 48 M with radius of 500 km. The detailed location are shown in Figures 10 – 12.

From seismic source map as shown in Figures 10 – 12 (megathrust and fault), there are several seismic source inside red circle where Kedaung Bridge located. The summary of potential seismic source inside red circle can be seen in Tables 1 and 2.

Table 1: Potential megathrust seismic zone.

No	Subduction Zone	Max Rec'd Mag.
1	Megathrust Jawa	M = 8.2
2	Megathrust Sumatra	M = 8.1

Table 2: Potential fault zone.

Fault		Max Rec'd Mag.
ID	Name	
14	Ketaun	M = 7.3
15	Musi	M = 7.2
16	Manna	M = 7.3
17	Kumering	M = 7.6
18	Semangko	M = 7.2
19	Sunda	M = 7.6
31	Opak (Jogja)	M = 7.8
32	Lembang	M = 7.6
33	Pati	M = 7.8
34	Lasem	M = 7.5

Maximum magnitude from data as shown in Tables 1 and 2 is Mw = 8.2 SR. This value is historical seismic ever recorded in the zone. This magnitude value can trigger liquefaction event in the area with high sand content.

2.4 Liquefaction Evaluation

Liquefaction of soil can be happened due to loss of strength in saturated and cohesion less soil. In this phenomena, pore water pressure will be increasing significantly, hence, effective stress of affected soil will be reduced. Rapid dynamic loading is main suspect of liquefaction phenomena. Earthquake and other rapid dynamic loading can trigger the increment of pore water pressure. In Indonesia, several liquefaction phenomena has been recorded. Most of them happened after earthquake event.

Method of liquefaction evaluation used is SPT (soil penetration test) based evaluation that is developed by United States' NCEER (National Center for Earthquake Engineering Research) in December 1997. T.L.Youd and I.M. Idriss are editors of NCEER. This method is using CRR (cyclic resistance ratio). Minimum magnitude of earthquake to trigger liquefaction based on this method is 7.5 SR (scale of Richer). In the other hand, this method has limitation. This method is applicable for (N1)60 $<$ 30; for (N1)60 $\geq$ 30, fine sand content is too dense to liquefied and this type of soil is classified as non-liquefiable soil (Ikhsan, 2011).

Researcher has analysed liquefaction in spreadsheet program and has considered limitation above. For (N1)60 $\geq$ 30, Researcher input maximum allowable value of 30. For instance, if (N1)60 = 45, Researcher only input maximum allowable value. In spreadsheet, the value becomes 30. This limitation has shown logic value of FS (factor of safety). Researcher only plot result of depth vs. FS for each borehole. The evaluation results are shown in Figures 13 – 16.

Red box in Figure 14 and Figure 16 indicate soil layer that has FS $<$ 1. This value indicate potential liquefaction in those layer. To classify the risk, the next chapter will explain and classify how above FS value has potential liquefaction. Any risk considered in above parameter will be explained below using Fuzzy based method.

3 NATIONAL INDONESIA CODE/STANDARD (SNI) AS INFERENCE SYSTEM

Indonesia has released standard code for geotechnical design called SNI 8460:2017 *Persyaratan Perancangan Geoteknik* (Geotechnical Design

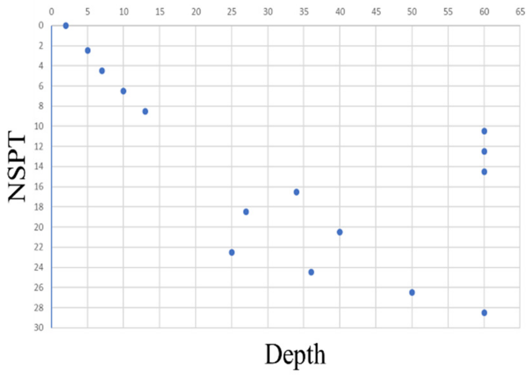


Figure 13: Depth vs NSPT for B1 soil profile.

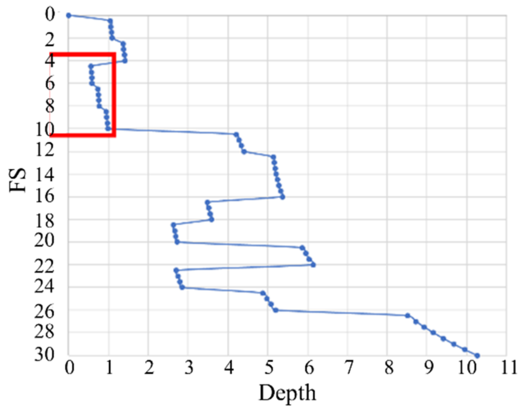


Figure 14: Depth vs FS for B1 soil profile.

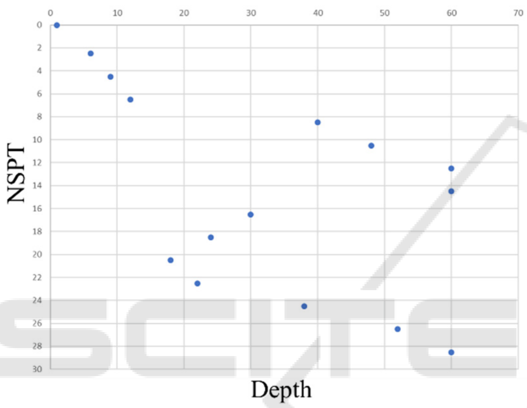


Figure 15: Depth vs NSPT for B2 soil profile.

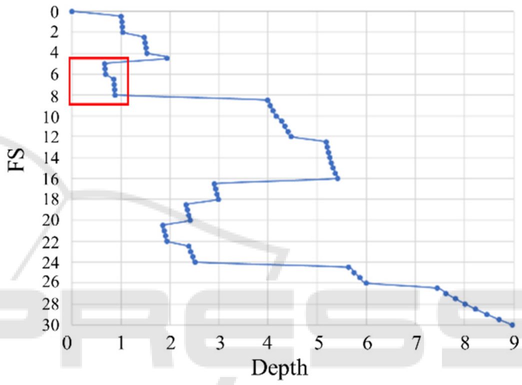


Figure 16: Depth vs FS for B2 soil profile.

Guidelines). This code will be used as inference system for risk analysis using Fuzzy-based method. This code is used as inference system because it contains expert overview about geotechnical aspects or parameter being described above.

This code is published by *Badan Standarisasi Nasional* (National Standarization Agency) of Indonesia. A group of geotechnical expert in Indonesia is then form a team to set this standard / code. The team consist of Indonesia Government (represented by experts from Ministry of General Works and Housing), civil engineering society (represented by *Himpunan Ahli Teknik Tanah Indonesia* / Indonesian Society for Geotechnical Engineering and *Himpunan Pengenmbangan Jalan Indonesia* / Indonesian Raod Development Association), university (represented by Tama Jagakarsa University, National Technological Institute) and private sector (represented by PT Belaputera Intiland and PT MBT).

3.1 Slope Stability Design Guidelines (Chapter 7 of SNI 8460:2017)

This code, generally, covers common technical requirement for artificial slope. And for natural slope, this require the engineer to check the natural slope stabilization where there will be development in any part of slope. The goal of slope stability checking is to design and review the safest and most economical slope design. Embankment is well covered by this code. In this code, several different analysis type shall be done to have board result of embankment condition. This code require at least short-term analyses (when embankment works finished), long-term analyses (for operational needs), sudden-draw down analyses (when embankment has high water table) and seismic analyses. The safety factor for soil slope and the criteria for seismic design as suggested by SNI 8460-2017 are shown in Tables 3 and 4 respectively.

Table 3: Safety Factor value for soil slope (SNI 8460-2017).

Costs and Consequences from failed slope	Level of uncertainty in the condition analysis	
	Low[a]	High[b]
Repair cost are equal to additional cost to design a more conservative slope	1.25	1.5
Repair cost are greater to additional cost to design a more conservative slope	2.5	2.0 or more
[a]The level of uncertainty in the analysis condition is categorized as low, if geological conditions can be understood, soil conditions are uniform, soil investigations are consistent, complete and logical to the conditions in the field.		
[a]The level of uncertainty in the analysis condition is categorized as high, if geological conditions are very complex, soil conditions are vary, soil investigations are inconsistent and unreliable.		

Tabel 4: Criteria for seismic design based on infrastructure designation (SNI 8460:2017).

Allotment	Design age (Years)	Probability Exceeded (%)	Return Period (Years)	Safety Criterions	Reference
Building and Non Building	50	2	2500	-	SNI 1726:2012
Conventional bridge	75	7	1000	-	SNI 2833:201X
Earth retaining wall, bridge abutment	75	7	1000	SF > 1.5 (against sliding when experiencing static load)	WSDOT, FHWA-NJ-2005-002
				SF > 2 (against overturning when experiencing static load)	
				SF > 1.1 (against pseudo static)	
Approach bridge's abutment	-	-	-	SF > 1.1	-
Dam	100	1	10000 Safety Evaluation Earthquake (SEE)	Uncontrolled water flow does not occurs	ICOLD No. 148-2016
				Deformation does not exceed 0.5 of height	
				Deformation of filters does not exceed 0.5 from filter thickness	
				Spillway shall still functional after earthquake event	
	100	50	145 Operating Basis Earthquake (OBE)	Minor damage occurs after earthquake	-
Dam Supplementary Building	50	2	2500	-	-
Tunnel	100	10	1000	-	-

3.2 Seismic Hazard Design Guidelines (Chapter 12 of SNI 8460: 2017)

Bridge is no different than any other civil structure or building. It is prone to earthquake event. In SNI 8460:2017, earth retaining wall and bridge abutment shall resist earthquake force with several minimum SF value. The criteria for seismic design is shown in Table 4.

3.3 Liquefaction Design Guideline

In this research, liquefaction analysis is conducted using Youd-Idriss Method. This method has final value, the SF value. Like the other parameter, this value has safe limitation. SF value for liquefaction analysis is at least 1 for the first 20 meter depth of granular soil layer with high water table. Triggering parameter for liquefaction is earthquake with minimum magnitude of SR (Scale of Richer) = 7.0. Kedaung Bridge is located in vulnerable tectonic plate with megathrust and fault seismic sources that have qualified to trigger liquefaction.

Tangerang is located in earthquake vurnerable zone. Maximum historical earthquake magnitude value in SR is 8.2. It comes from Java Magathrust. Liquefaction around B1 and B2 location is considered safe. Liquefaction (with earthquake triggering value, SR = 8.2) may happen in depth 4 ~ 10 meter of soil layer.

4 RISK ANALYSIS USING FUZZY –BASED METHOD

Whole parameter and evaluation works above have conducted, the next step is to weighting the risk based on Indonesian Standard Codes (SNI / *Standar Nasional Indonesia*).

4.1 Fuzzy Logic

Fuzzy logic is a logic to describe imprecision, to approximate reasoning and to explain uncertainty of something. Fuzzy logic can be viewed as an attempt at formalization / mechanization of two remarkable human capabilities; First, the capability to converse, to make reason, and to make rational decision in an environment of imprecision, uncertainty, incompleteness of information, conflicting information, partiality of truth and partiality of possibility; Second, the capability to perform a wide variety of physical and mental task without any measurement and any computations (Zadeh, 2008).

Fuzzy logic can describe normal human languange. This method use neutral way of how human thinking and reasoning. Fuzzy logic use input data and process it with some reasoning (we may call itu as "blackbox"). This blackbox contains a sort of reasoning. And after the input has been processed, the output can be obtained.

5 CONCLUSION

This research is still in progress. Especially in the risk analyses using Fuzzy-based method in civil engineering world. We still in progress to clarify that Fuzzy-based methods can be used in Civil Engineering. In this research, we take advantages of Fuzzy logic in civil engineering. Kedaung Bridge abutments have affordable SF value in long-term, short-term and seismic condition. SF value vary from 1.183 to 2.092.

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