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Comparison of Uncertainty Methods for Pipe Deflection Calculation

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Abstract

Reliability of pipe structure is one aspect to be considered in reactor safety analysis. MSC NASTRAN is a computer code that can be used to calculate pipe deflection for reliability evaluation. MSC PATRAN can be used to generate input for this code. Uncertainty evaluation needs to be done in the input variable to understand uncertainty range in the analysis results. A computer code for evaluating structure reliability has been developed in our previous study. The code has implemented latin hypercube sampling (LHS) to assess uncertainty in the input variable, such as load and modulus of elasticity. In this study, comparison of two uncertainty methods, i.e. simple random sampling (SRS) and LHS, was carried out for the developed software. The comparison was subjected to pipe deflection calculation using 100 samples. Comparison analysis shows that LHS method produces a robust mean of variance for all sample size. The results also confirm that variance of pipe deflection using LHS is smaller by 3% than SRS one. It can be concluded that LHS is appropriate to be implemented for uncertainty analysis in the developed code.

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1. Introduction

In the design of nuclear reactor, safety factor is the most important consideration. One consideration in the safety analysis is pipe structure reliability. Computer software which are commonly used to analyze pipe structure and pressure vessel integrity in the nuclear reactor are MSC NASTRAN and ANSYS [1].

Regarding pipe deflection calculation, there are three phases that need to be completed, i.e. pre-processor, processor and post-processor phases. In the pre-processor phase, MSC PATRAN is used and uncertainty value is still not considered [2]. Output file from MSC PATRAN becomes input file for MSC NASTRAN. Analysis of the uncertainty on the final result is affected by the uncertainties of input. Therefore the addition of uncertainties in the input variables needs to be evaluated. Sensitivity analysis reflects the relationship between the uncertainty in the results and input variables [3, 4, 5].

Uncertainties in the predictions of structural strength can be calculated using simulation techniques, such as Monte Carlo simulation. The strength of structural design depends on basic strength variables of both material and geometrical aspects, such as material's yield strength, plate thickness and modulus of elasticity [6]. The probability of failure can be

caused by the uncertainties associated with the load and material properties. This probability can be estimated using a Monte Carlo simulation [3].

A computer code which has considered uncertainty factor in the input variable has been developed. Input variables in which the uncertainty are taken into account in the code are load and modulus of elasticity [2]. Uncertainty calculation in load and modulus of elasticity can also be done simultaneously using fuzzy finite element method [7]. The computer program makes it possible to communicate with MSC PATRAN in the pre-processor phase and software MSC NASTRAN in the calculation process.

Latin Hypercube Sampling (LHS) uncertainty method was used in the development of computer program. An evaluation was carried to this program using stress and deflection value resulted in MSC NASTRAN [2]. LHS method was used to increase sampling eficiency and computation time could be reduced approximately by 50% [8]. The objective of sampling is to reduce the variance in process of mean estimation. Sampling technique is useful for increasing sample availability in the function being analyzed. Reducing of simulation number in the analysis will reduce the computation process.

Simple Random Sampling (SRS) is a basic sampling technique widely used for benchmarking/comparison. This method give random number and desired variable value according to the type of probability distribution. LHS is an evolutionary method from stratified sampling method. In case for monotonic function, this method is better than SRS, but limited for normal, triangular and uniform distribution [9]. Comparison results between SRS method and LHS method showed that under small amount of sample, there was no significant difference in prediction of mean value and variance. LHS method provided a more robust result rather than stratified sampling method [10].

In this study, comparative study using developed computer program and MSC PATRAN-MSC NASTRAN was carried out to be subjected to SRS and LHS uncertainty method. The objective of this study is to obtain an approriate uncertainty method which match with the computer program for simulation using MSC PATRAN-MSC NASTRAN. A small variance value on deflection number was used as parameter of conformity. Comparison analysis shows that LHS method produces a robust mean of variance for all sample size.

2. Theory

The continuous increase in data size keeps chalenging to estimate the characteristic of the population effective and efficient. Sampling is a standard statistical procedure to estimate or learn something from the population at low cost. Sampling is a systematic way of reducing the data size while maintaining essential characteristic of the data set [10,11].

Simple Random Sampling

Simple Random Sampling (SRS) is a basic sampling techniques are often used as the basis for the development and comparison of more complex sampling techniques. Basic principle of SRS is for each sample has the same probability to be chosen. This method is working by generating random number and obtain variable value correspond to type of data distribution. Mean is estimated according to statistical rule as shown in Eq. (1) below [10]:

$$\overline{a_{simple}} = \frac{1}{N} \sum_{i=1}^{N} a_i$$

(1)

N is multiple number of sample and a_i is generated random number. Variance value is formulated as Eq. (2) below [10] :

$$Var(a_{simple}) = \frac{1}{N-1} \sum_{i=1}^{N} (a_i - \overline{a}_{simple})^2 \tag{2}$$

Mean variance estimation is formulated in Eq. (3) below [10] :

$$Var(\overline{a}_{simple}) = \frac{1}{N} Var(a_{simple}) \tag{3}$$

Latin Hypercube Sampling

Latin Hypercube Sampling (LHS) is evolutionary sampling method from stratification sampling. This method is working by dividing into levels and generate samples until values from different levels were obtained [10]. LHS is one of method to obtain uncertainty. Variable with number of "k", $X_1,............X_k$, LHS choose different value "n" on each "k". Each variable was divided into "n" interval, and for each interval, one value with same probability was chosen [12]. Mean value estimation and variance on LHS is the same as those on SRS, as describe in Eq. 4 and 5 [10].

$$\overline{a}_{LHS} = \frac{1}{N} \sum_{i=1}^{N} \overline{a}_i \tag{4}$$

$$Var(a_{LHS}) = \frac{1}{N-1} \sum_{i=1}^{N} (a_i - \overline{a}_{LHS})^2 \tag{5}$$

Mean variance estimation on LHS describe in Eq. 6 below [10].

$$Var(\overline{a}_{LHS}) = \frac{1}{N} (a_{LHS}) + \frac{N-1}{N} Cov(A_1, A_2) \tag{6}$$

$Cov(A_1, A_2)$ is covarian value between input variable.

3. Methodology

The procedure in this study is shown in Fig. 1.

There are three phases in calculation of pipe deflection. First phase is building the model, which the input file for MSC NASTRAN was built using MSC PATRAN according to spesification shown in Table 1. Value of load and modulus of elasticity according to input variable shown in Table 2. Load parameter in Table 2 has a range ±10 % from total weight which shown in Table 1. Parameter value of elasticity modulus use varians 5% from mean value.The modulus of Elasticity used in this study referred to material of Stainless Steel Pipe based on ASTM A 312 TP 316 L [7]. Result of this process is input file with bdf extension.

The second phase is generation of variable data using value shown in Table 2. The data generation were performed by developed computer program in previous research [2]. Hundred data generated in this process then to be used for substituting load value and modulus of elasticity value in bdf file. There two sets of data generated in this process, that are one data set generated by simple random sampling and the other one by Latin Hypercube Sampling. In this process, there are two sets file for MSC NASTRAN input, each set contains 100 bdf files.
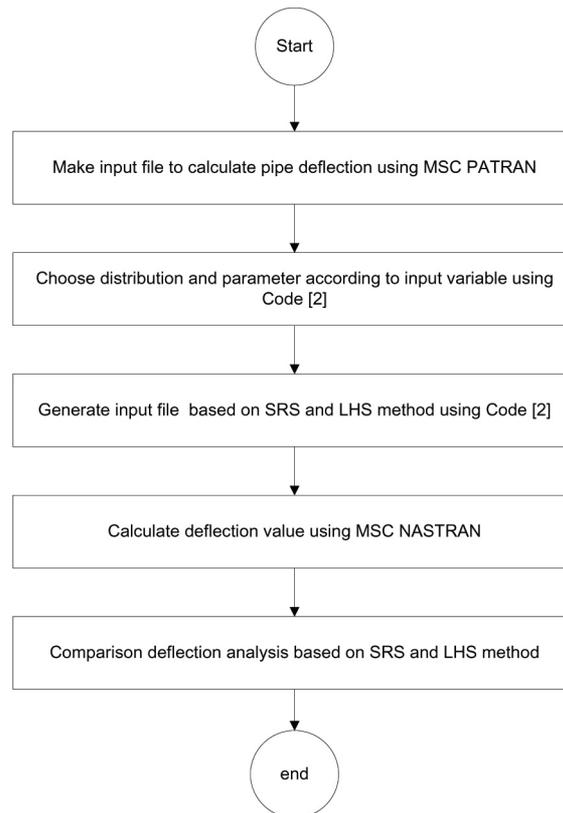
Figure 1: Research flow diagram.

The third phase is calculation phase using MSC NASTRAN to obtain pipe deflection. In this calculation, material pipe is considered as isotropic and linear elastics. While calculation mode were performed under linier static. Calculation results in this process then examined using MSC PATRAN (post processor phase).

TABLE 1: Pipe data use to simulation [7].

No	Variable	Value
1	Length	11 m
2	Inner diameter	0.3071 m
3	Outer diameter	0.3239 m
4	Total weight(Load)	1367.8 N/m
5	Elasticity Modulus	195122e06 Pa

TABLE 2: Distribution parameter.

No	Input Variabel	Distribusion	Parameter
1	Load	Uniform	[1231.02 N/m, 1504.58 N/m]
2	Elasticity Modulus	Normal	[195122e6 Pa, 98772.97 Pa]

Besides three stages as described above, in order to examine variance of data obtained by Simple Random Sampling method and Latin Hypercube Sampling method, generation data were performed three times to generate three different sample sizes, that 20, 100 and 1000. The data generation were replicated three times for each sample size. Cumulative Distribution Function was used as parameter to compare data stability in LHS method and SRS method [8].

4. Results and Discussions

Distribution of data generation in phase two, were shown in Fig. 2. Figure 2a represents result by SRS method and Fig. 2b by LHS method, respectively. These data contains 20 samples. In Fig. 2b Modulus of elasticity distributed evenly in each stratum. It can be said that LHS method provide a better distribution rather than SRS method.
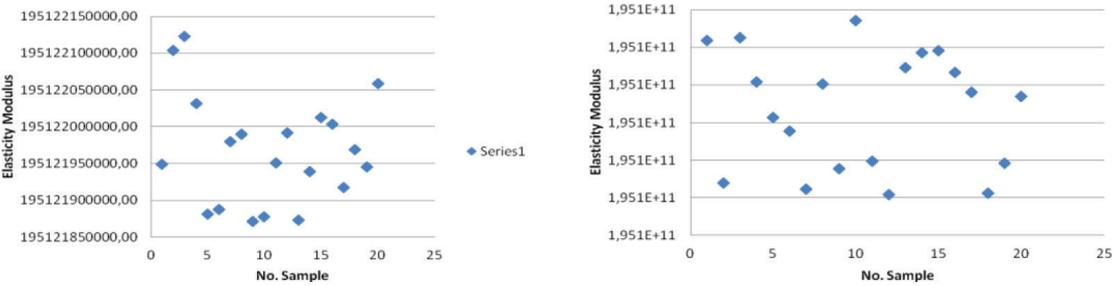

Figure 2: (a) Distribution of elasticity modulus –SRS; (b) Distribution of elasticity modulus–LHS.

Cumulativ Distribution Function (CDF) calculation results of LHS method and SRS method were shown in Fig. 3 and Fig. 4. Figure 3 and Fig. 4 represents for 20 and 100 sample size, respectively. By using 20 sample size, the variance between replication in SRS, is smaller/narrower rather than in LHS. It means, for small sample size, SRS method provides good repeatability in data generation. Variance between replication show uncertainty from sampling method. Result from replication can be used to estimate confidence interval and appropriate sample size to get robust statistic result [13].
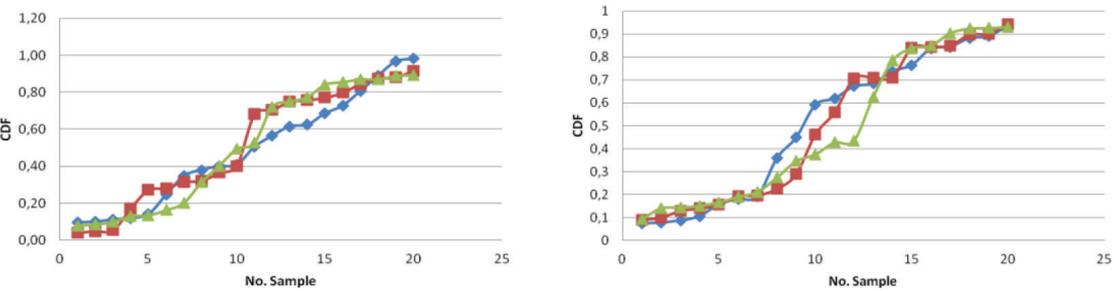

Figure 3: (a) CDF of Elasticity Modulus SRS–20 sample ; (b) CDF of Elasticity Modulus LHS–20 sample.

For larger sample size (100 samples in Fig. 4) the variance in both methods no significant difference. It means, in three replication with 100 samples, SRS and LHS method have same variance stability.
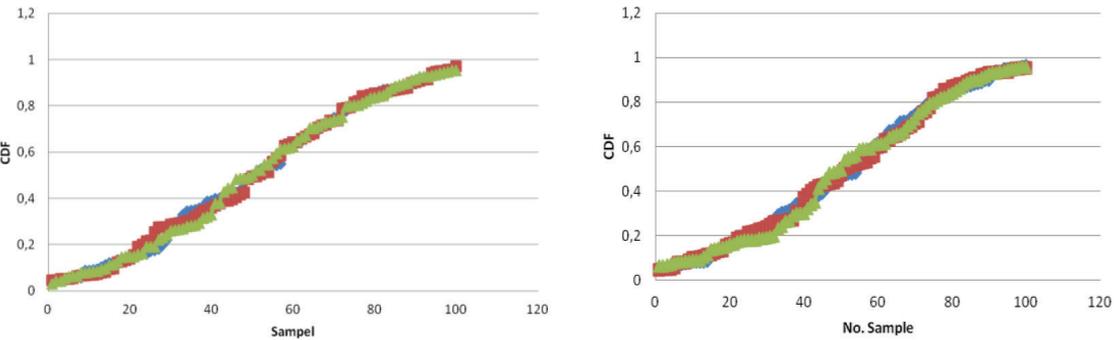

Figure 4: (a) CDF of Elasticity Modulus SRS–100 sample; (b) CDF of Elasticity Modulus LHS–100 sample.

Mean of variance for three sample sizes calculated by SRS and LHS method were shown in Table 3. For both variable, load and elasticty modulus, mean of variance of SRS method has smaller value than LHS. It occured for all of sample size, except for 20 sample size in elasticity modulus variable, where LHS provided small variance than SRS. This result shows that LHS uncertainty method does not always give a small variance than SRS.

TABLE 3: Mean of variance of input variable.

Variable	Sample Size	Uncertainty Method	
		SRS	LHS
Load	20	4790.09	6278.89
	100	6254.40	6513.59
	1000	6178.56	6247.08
Elasticity Modulus	20	7.49E9	7.46E9
	100	5.82E9	6.56E9
	1000	6.58E9	6.59E9

Figure 5 shows the relation between mean of variance and sample size. Figure 5a shows mean of variance for load variable and Fig. 5b shows mean of variace for elasticity modulus. The sample sizes are 20,100 and 1000. For load variable (Fig. 5a), mean of variace with sample size of 100 and 1000 looks like no significant difference. Significant difference between LHS and SRS occurred for sample size of 20. Meanwhile, for elasticity modulus variable (Fig. 5b), mean of variance in LHS method has no significant difference for sample size of 100 and 1000 (remain constant). The other hand, mean of variance in SRS method decrease at sample size of 100 and then increase at sample size of 1000. It could be concluded that LHS method provide more stable mean of variance than SRS method.
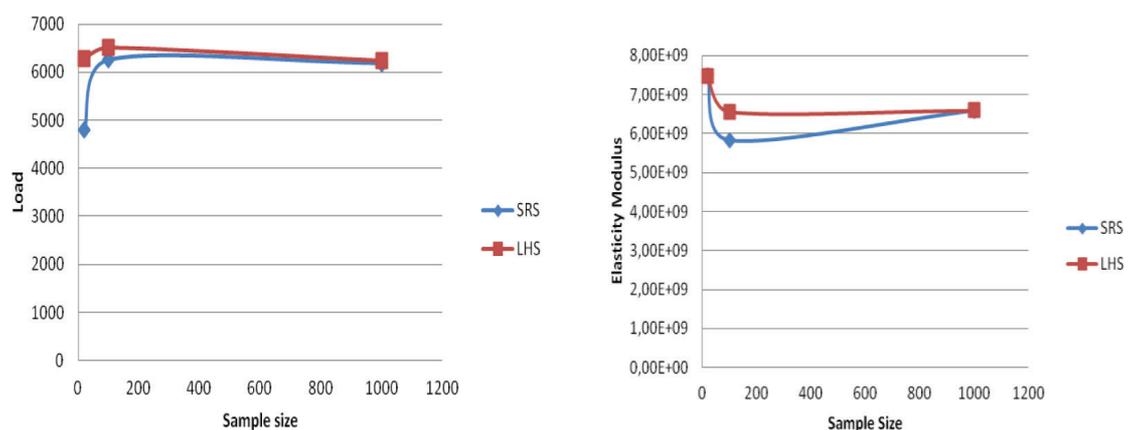

Figure 5: (a) Graph between mean of variance of load and sample size; (b) Graph between mean of variance of elasticity modulus and sample size.

Calculation results of pipe deflection using MSC NASTRAN were shown in Table 4. In the same table, result from calculation using ANSYS [7] are shown for the same case. Calculation from different software produces 0.8% differences. It could be said that no different result between MSC NASTRAN and ANSYS. Calculation result of pipe deflection with uncertainty considerations were also presented in Table 4. The calculation based on sample size of 100

using LHS and SRS method. Both methods produces variance of deflection value of 6.51E-07 for SRS method and 6.26E-07 for LHS method. It means, LHS' variance is 3% smaller than SRS' variance. This result show that there is no significant difference between SRS and LHS.

TABLE 4: Result of displacement calculation.

Calculation	Pipe Deflection	Variance
Without uncertainty with ANSYS [7]	12.89 mm	-
Without uncertainty with MSC NASTRAN	13.00 mm	
Uncertainty, SRS with MSC NASTRAN	13.03 mm	6.51E-07
Uncertainty, LHS with MSC NASTRAN	12.93 mm	6.26E-07

Comparison analysis of uncertainty method to calculate pipe deflection shows that LHS method produces a robust mean of variance for all sample size. The use of LHS as a uncertainty method in the developed code is appropriate.

5. Conclusion

Comparison of two uncertainty methods, i.e. simple random sampling (SRS) and LHS, has been carried out. Comparison analysis shows that LHS method produces a robust mean of variance for all sample size. The results also confirm that variance of pipe deflection using LHS is smaller by 3% than SRS one. It can be concluded that LHS is appropriate to be implemented for uncertainty analysis.

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