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Determining Confidence for Evaluation of Vulnerability In Reinforced Concrete Frames with Shear Wall

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ABSTRACT

In this paper, in order to evaluate the vulnerability of concrete frames with shear wall, the maximum displacement of stories as an indexes is used. For this purpose, a concrete frame with shear wall and with 4–stories and 4-bays, which its loading is according to principles written in regulations related to seismic resistant design of building in the case of earthquake occurrence (standard NO:2800 - third edit), has been selected and designed. This frame are run in nonlinear dynamic analysis by IDARC (ver. 6.0) under 30 records of 0.1g to 1.5 g accelerations, and the maximum displacement in the stories is calculated based on each records and each acceleration . The appropriate statistic distribution is determined for the data of damage. At the end, based on the theorem of "central limit", a confidence interval of 95% is determined for parameters including mean and standard deviation in the considered distribution. In order to validate the functions and the obtained confidence interval, the results are tested according to earthquake records in Tabbas, IRAN. In view of the mentioned considerations, Log-Normal Distribution is the best function among the statistic functions related to the maximum displacement in stories within the concrete frame with shear wall and with 4–stories and 4-bays, under the constant record of 0.1g to 1.5 g acceleration.

Keyword: Maximum Displacement in Stories, Concrete Frame with shear wall, Log-Normal Distribution, Confidence interval.

INTRODUCTION

Many earthquakes have occurred on the earth, and in view of the fact that intensity and content of the frequency in each record of an earthquake varied with other records, it is so hard and even impossible to reach an absolute conclusion from evaluating the vulnerability of

concrete frames by using some analytical approaches. Nowadays, in order to evaluate the vulnerability of concrete frames in a large scale, it is applied the statistic distribution function. At first for a sample which has all characteristics of a society, an appropriate statistic distribution function is selected, and then statistic approaches are applied to develop this statistic distribution function to the society.

Gatherine Ann Pagni from Washington University (2000) has suggested a damage model for components of old reinforced concrete. He introduced 12 states of damages for members of concrete. Those 12 states of damage included primary crack at the connection between beam to column, a crack at the connection between members of concrete with 5 mm width until fracturing and crushing the concrete. Mr. Pagni divided the mentioned 12 states of damages into 2 categories including cracking and crushing concrete, then among the statistic distribution functions such as Normal, Log-Normal, Weibul and Beta, he specified the best distribution by using Maximum Likelihood method (Pagni, 2003) .Singhal & Kiremidjian (1998) evaluated frangibility curves with regard to the observed data in a structure with one story. They used Park-Ang index to evaluate the vulnerability of a structure and expressed the rate of damage due to different earthquakes based on statistic distribution functions. Tanaka et al (2000) applied Log-Normal distribution to calibrate frangibility curves. He classified 3683 bridges into 5 categories, defined the rate of the damage based on all 5 categories, then he analyzed the parameters of Log-Normal distributions. (Gian Paolo Cimellaro, 2006)

Introducing the frame and earthquakes studied

To determine distribution function for index of maximum displacements in stories, at first a concrete frame with shear wall and with 4–stories and 4-bays,was selected, then according to principles written in regulations related to seismic resistant design of building in the case of earthquake occurrence (standard NO:2800 - third edit), lateral loading in the building was accomplished, also at next step the building was designed based on principles written in regulations regarding to designing reinforced concrete buildings.

Considering the effects of the primary design on the results from final analysis, the following points (table 1) were taken into account during the designing and analyzing the desired frames. (Mehdi Nikoo, 2009)

- Analyzing and designing the buildings has been conducted within elastic limit. However Non-Linear Dynamic Analysis Software for Reinforced Concrete buildings (IDARC Software) was applied to study

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building behaviors within nonlinear limit, to calculate input energy and hysteretic energy, as well as to study the vulnerability of the buildings. (R.E.Valles, 1996)

- Spectral dynamic analyzing of models was accomplished by using modes analysis and considering all modes, based on the hypothesis regarding the elastic and linear behavior of buildings. In this analysis, the spectral standard 2800 with attenuation ratio $(\xi = 0.05)$ was used. (standard, 2005)

Table 1. The information related to the concrete frame with shear wall.

frame	**Special type of reinforced concrete**
Elevation of each stories	3.2 m
Bays at each frame	5 m
Steel ratio (ρ)	In columns of building $0.015 \le \rho \le 0.035$
Importance factor of structure	Group 2
Dead load of roof	600 Kg/m2
Live load of roof	175 Kg/m2
Dead load of stories	500 Kg/m2
Live load of stories	200 Kg/m2
Seismic hazard	High macrizonation hazard
Type of land	Soil of type II

One of the most effective parameters on input energy imposed to buildings is the applied accelerogram in the seismic analysis. The rate of input energy imposed to buildings are affected from an input earthquake more than the building characteristics, however these studies were more about buildings with single degree of free (SDOF), according to the studies by other researchers, this mentioned fact is confirmed for structures with multiple degree of free (MDOF). Thus in order to select the accelerograms, it is necessary to take into accounts various characteristics of them. So in this research, 30 earthquakes occurred in abroad were run in the non-linear dynamic analysis by using IDARC software. The characteristics of those 30 earthquakes were shown in table (2). (Mehdi Nikoo, 2009)

In this research, the concrete frame with shear wall was run in the non-linear dynamic analysis. This analysis was conducted based on accelerations of $0.1g, 0.2g, ..., 1.4g, 1.5g$. Therefore the number of analysis for the studied frame is calculated as equ. (1):

$$\text{number of analysis in frame} = 450 = \text{one frame} \times 30 \text{ records of earthquakes} \times 15 \text{ accelerations} \tag{1}$$

After each analysis, the maximum displacement in stories was extracted from the software. Because there was a high volume of data and in order to reach the desired results, the data must be classified. For this reason, in a station, for example "*Hollywood Storage Station of Northridge earthquake 1994*", the acceleration is increased from $0.1g$ to $1.5g$. Therefore we have 30 sets of numbers, which in each set of numbers there are 15 data approximately. (Mehdi Nikoo, 2009)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test is a simple non-parametric approach which determines the appropriate statistic distribution for the experimental data. Beside another approach is the Chi-square (χ^2) approach. Kolmogorov-Smirnov Test works based on a particular table. If the test statistic is less than the value written in the table, the Hypothesis of "zero"[1] will be accepted; otherwise it will be rejected [6]. The test statistic is equal to the maximum absolute of differences between observed frequency and theoretical frequency, which is shown in equ. (2):

$$Z = \text{Maximum} \, | F_e - F_o | \tag{2}$$

Where Z is a test statistic, and F_e and F_O are theoretical frequency and observed frequency, respectively. (Brownlee, 1956)

- In Z statistic, the obtained number is between zero and one, as much as that number is near to one, it is indicated that the set of data are more conformable along with the distribution tested.

[1] *Hypothesis zero (h_0): there are no meaningful differences between the expected and observed frequency.*

- In Z statistic, if the obtained number is less than 0.05, it is indicated that the selected distribution is not conformable along with the data.
- If several distributions are tested by Kolmogorov-Smirnov Test, the best distribution is the one that its Z statistic is the highest number in this table. (Brownlee, 1956)

Table 2 . earthquake characteristics of selected accelerogram

No	Name Of abroad Earthquake	stations	PGA
num1	Imperial Valley 1979	Chihuahua	0.254
num 2	Imperial Valley 1979	Chihuahua	0.27
num 3	Northridge 1994	Hollywood Storage	0.231
num 4	San Fernando 1971	Lake Hughes #1	0.145
num 5	San Fernando 1971	Hollywood Stor Lot	0.21
num 6	Super Stition Hills 1987	Wildlife Liquefaction Arrey	0.134
num 7	Super Stition Hills 1987	Wildlife Liquefaction Arrey	0.134
num 8	Super Stition Hills 1987	Salton Sea Wildlife Refuge	0.119
num 9	Super Stition Hills 1987	Plaster City	0.186
num 10	Super Stition Hills 1987	Calipatria Fire Station	0.247
num 11	Landers 1992	Barstow	0.135
num 12	Cape Mendocino 1992	Rio Dell Overpass	0.385
num 13	Cape Mendocino 1992	Rio Dell Overpass	0.549
num 14	Coalinga 1983	Parkfield - Fault Zone 3	0.164
num 15	Whittier Narrows 1987	Beverly Hills	0.126
num 16	Northridge, 1994	LA, Baldwin Hills	0.239
num 17	Imperial Valley, 1979	El Centro Array #12	0.143
num 18	Loma Prieta, 1989	Anderson Dam Downstream	0.24
num 19	Loma Prieta, 1989	Anderson Dam Downstream	0.247
num 20	Loma Prieta, 1989	Agnews State Hospital	0.159
num 21	Loma Prieta, 1989	Anderson Dam Downstream	0.244
num 22	Loma Prieta, 1989	Coyote Lake Dam Downstream	0.179
num 23	Imperial Valley, 1979	Cucapah	0.309
num 24	Loma Prieta, 1989	Sunnyvale Colton Ave	0.207
num 25	Imperial Valley, 1979	El Centro Array #13	0.117
num 26	Imperial Valley, 1979	Westmoreland Fire Station	0.074
num 27	Loma Prieta, 1989	Sunnyvale Colton Ave	0.209
num 28	Imperial Valley, 1979	El Centro Array #13	0.139
num 29	Imperial Valley, 1979	Westmoreland Fire Station	0.11
num 30	Loma Prieta, 1989	Hollister Diff. Array	0.269

Determining the appropriate statistic distribution for maximum displacements in stories of the concrete frame, in a station

In this research, the extracted data by Kolmogorov-Smirnov Test, was tested for 4 types of distributions such as Normal, Log-Normal, Exponential and Uniform distribution. It was indicated that in a certain station when the acceleration was increased, the most appropriate distribution conformable along with the data was Log-Normal. In table (3), it was shown the obtained results from Log-Normal distribution. According to table (3), the value of Asymp.Sig (2-tailed) parameter (which is the Z statistic) was more than 0.412 in all the stations, and in 18 stations it was between 0.8 to 1.0 , thus Log-Normal distribution is the best for the data. (Mehdi Nikoo, 2009)

Probability Plot (P-P) was used to represent the abovementioned convergence of the data with a kind of distribution observably. In these diagrams, vertical axis of likelihood values and horizontal axis of all the observed data are indicated in terms of a specific scale. This selected scale must be the one which all the data can be included in the diagrams, according to the desired scale. Diagonal intervals[2] shown in the diagrams stated the considered distribution. In the illustrated diagrams, P is a constant value, indicating the convergence of the data with the considered distribution. It is between zero and one, the more near to number one, the more convergent the data with the distribution. If "P" is less than 0.05, it is indicated that data are conformable along Log-Normal distribution.

For the reason that there are 30 stations to study in this research, 3 stations were randomly selected, including station number 10, 17, 28, and P-P (Probability Plot) was obtained for 3 distributions such as Log-

[2]- *diagonal intervals: between two drawn slanting lines of figure(1) in a diagram*

Normal, Normal and Exponential. In figure (1), it is shown the plotted diagrams. In view of these diagrams, it is concluded that the maximum displacement in stories of the *concrete frame with shear wall and with 4–stories and 4-bays,* in a certain station were conformable along with the Log-Normal distribution.

After it was determined that the maximum displacement in stories have had the Log-Normal distribution, then we tried to focus on plotting the Log-Normal curves. The curves shown in figure (2) were plotted for station 10, 17, and 28. In order to draw Log-Normal curves, “*MINITAB”* statistical analysis software was applied. There are 3 parameters such as *N*, *Scale* and *Loc* in the graphs of the Log-Normal curves, where: *N*: number of data; *Scale*: std. deviation of data (standard deviation of data); *Loc*: mean data, in Log-Normal curves. In these curves, the horizontal axis indicated the index for the maximum displacement in stories and the vertical axis indicated the frequency of the relevant data.

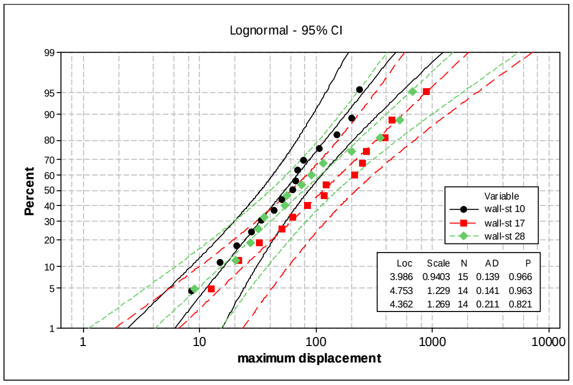

Fig1.a. Log-normal Distribution

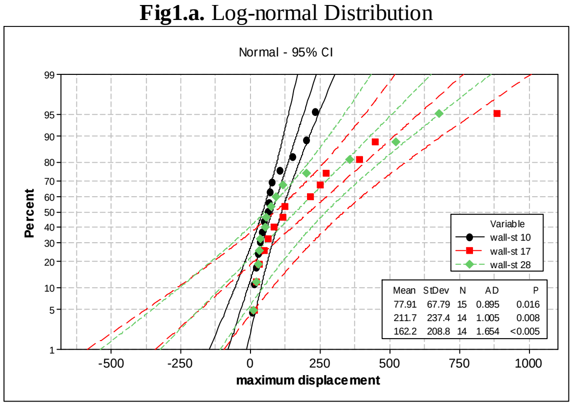

Fig1.b. normal Distribution

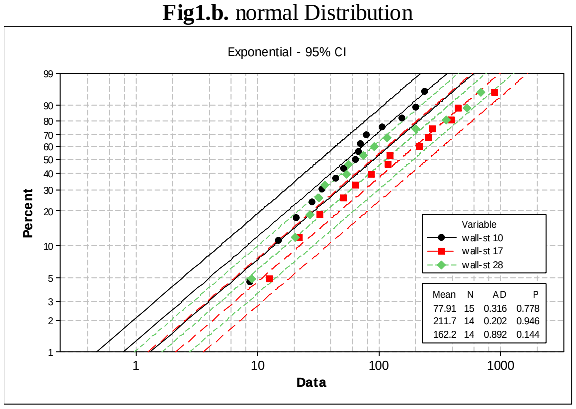

Fig1.c. Exponentail Distribution

Fig 1. Probability Plot diagram for distribution index of maximum displacement in stories at station 10, 17, 28

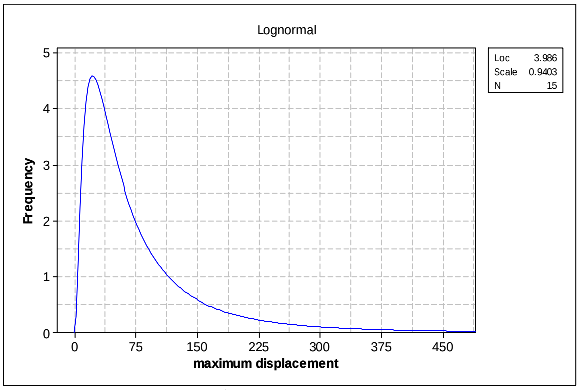

Fig2.a. Station 10

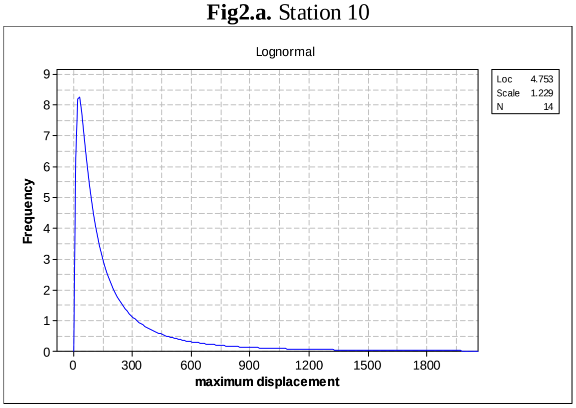

Fig2.b. Station 17

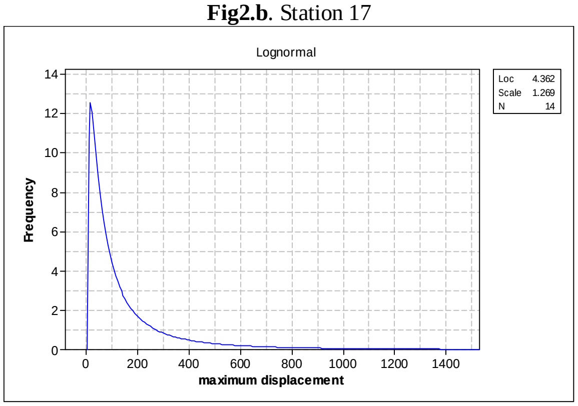

Fig2.c. Station 28

Fig 2. The Log-Normal distribution for the maximum displacement in stories

Table 3. Kolmogorov-Smirnov Test to represent Log-Normal distribution for the maximum displacement in stories of the wall concrete frame with 4- stories and 4 bays in the fixed stations and various accelerations

num 15	num 14	num 13	num 12	num 11	num 10	num 9	num 8	num 7	num 6	num 5	num 4	num 3	num 2	num 1	Station Number	
15	13	15	15	15	15	14	14	15	14	15	15	15	13	13	N	
4.8381	5.1835	4.7593	4.9820	4.6591	3.9860	4.9846	4.4644	4.9792	4.5650	4.8511	5.0427	5.0526	4.7469	4.9108	Mean	Normal Parameters(a,b)
1.0008	1.3767	0.8219	1.4037	1.3713	0.9403	1.1918	1.3940	1.2734	1.1607	1.3941	1.4659	1.4418	1.3075	1.2381	Std. Deviation	
.121	.191	.136	.197	.173	.102	.103	.211	.124	.145	.159	.227	.153	.119	.189	Absolute	Most Extreme Differences
.104	.132	.077	.133	.113	.081	.077	.163	.086	.088	.113	.174	.118	.103	.170	Positive	
-.121	-.191	-.136	-.197	-.173	-.102	-.103	-.211	-.124	-.145	-.159	-.227	-.153	-.119	-.189	Negative	
.469	.690	.528	.761	.671	.397	.386	.788	.481	.541	.616	.878	.594	.429	.683	Kolmogorov-Smirnov Z	
.980	.727	.943	.608	.758	.998	.998	.563	.975	.932	.842	.424	.872	.993	.740	Asymp. Sig. (2-tailed)	

Table3.a. Log-Normal distribution of station 1 to 15

num 30	num 29	num 28	num 27	num 26	num 25	num 24	num 23	num 22	num 21	num 20	num 19	num 18	num 17	num 16	Station Number	
13	15	14	14	14	14	15	15	14	14	14	14	13	14	15	N	
5.0316	4.7267	4.3622	4.6091	4.9487	4.8654	4.9565	4.6330	4.6338	4.6567	4.6506	4.5859	4.8933	4.7527	4.7280	Mean	Normal Parameters(a,b)
1.3142	1.1507	1.2688	1.1186	1.3572	1.3879	1.4436	1.2817	0.9541	1.1168	1.2234	1.0695	1.2955	1.2291	1.4236	Std. Deviation	
.166	.176	.106	.121	.148	.165	.182	.229	.154	.231	.137	.228	.209	.121	.146	Absolute	Most Extreme Differences
.109	.136	.106	.105	.103	.098	.164	.130	.107	.151	.077	.127	.146	.065	.146	Positive	
-.166	-.176	-.098	-.121	-.148	-.165	-.182	-.229	-.154	-.231	-.137	-.228	-.209	-.121	-.139	Negative	
.598	.681	.398	.454	.553	.616	.705	.886	.576	.866	.513	.855	.754	.452	.567	Kolmogorov-Smirnov Z	
.866	.742	.997	.986	.920	.842	.703	.412	.895	.442	.955	.458	.620	.987	.905	Asymp. Sig. (2-tailed)	

Table3.b. Log-Normal distribution of station 16 to 30

Determining confidence interval of 95% for parameters including mean and standard deviation in the Log-Normal distribution

In the Log-Normal distribution function, there is density function as follow in equ. (3), also there are two parameters including mean (μ) and standard deviation (ξ), that the confidance interval should be defined for both of these parameters. In view of the fact that there are 30 Log-Normal distributions in this research, so the number of each parameter (mean and standard deviations) will be 30. (Siegel. S, 1998)

(3) $$f(x;\mu;\delta)=\frac{1}{x\sqrt{2\pi\delta^2}}\exp\left[-\frac{1}{2\delta^2}(\log x-\mu)^2\right]x>0$$

30 data which each of them expressed the parameter of Mean in a Log-Normal distribution, are the numbers written in the row in front of "Mean" in table (3). In statistics, according to the theorem of "central limit", when the observed data have Normal distribution, their means also have Normal distribution and equation (4) is used to obtain the confidence interval, as follow:

(4) $$\overline{X}_{\bar{x}}-Z_{\frac{\alpha}{2}}.\delta_{\bar{x}}<\mu_{\bar{x}}<\overline{X}_{\bar{x}}+Z_{\frac{\alpha}{2}}.\delta_{\bar{x}}$$

$\overline{X}_{\bar{x}}$:the mean of 30 mean data which is equal to 4.7679 and $\delta_{\bar{x}}$:standard deviation for the mean of 30 data which is equal to 0.2428. α :first type of error, because the defined confidence interval is 95%, α should be considered 0.05, also because the type of distribution is Log-Normal, as well as it is a two side distribution, and it must be used the value of $\frac{\alpha}{2}$. If the selected samples[3] have Mean $\left(\bar{x}\right)$ and standard deviation (δ) and the set of the extracted data from samples have the distribution similar to the normal, then the mean μ in the set of data have distribution "***t***" as $t=\frac{\bar{x}-\mu}{\delta}$. Now because the number of samples is more than 25, distribution "***t***" tends to *Z* distribution and $Z_{\frac{\alpha}{2}}$ should be obtained from the table of *Z* standard normal and put it in equ. (4). In this research, since $\alpha=0.05$, so by taking Z from standard normal table, $Z_{\frac{0.05}{2}}=1.96$.

(5) $$4.7679-1.96\times 0.2428<\mu_x<4.7679+1.96\times 0.2428\rightarrow 4.2920<\mu_x<5.2438$$

Therefore, the value of the parameter related to the mean log-normal distribution will be in the range of $[4.29,5.24]$ with likelihood of 95%. 30 data which each of them expressed the parameter of std. Deviation in a Log-Normal distribution, are the numbers written in front of "std. Deviation" in table (3). In order to calculate the confidence interval of variance, at first it must be ensured that the observed data of the variance have a distribution similar to Normal. Since the observed data itself have Normal distribution, and to calculate the variance the observed data should be power 2 – to be square, thus Normal distribution change to distribution of Chi-square $\left(\chi^2\right)$. In the equation of $\sum\frac{(x_i-\bar{x})^2}{n-1}$ where parameter of X_i is Normal, according to the theorem of central limit, if parameter "n" is increased, the distribution of χ^2 will change to Normal distribution. [7] Therefore it must be determined to what extent this distribution is similar to normal. So to calculate the confidence interval of variance, at first the testing hypothesis related to "the variance parameters being Normal" should be calculated. The testing hypothesis related to "the variance parameters of variance being Normal" is run in "MINITAB" software. This software produce a consonant value named P_{value}, if that value is more than 0.05; the observed data of the variance have a distribution similar to normal. Figure (3) was shown the value of P_{value} for the maximum displacement in stories. $P_{value}=0.077$, because this value is more than 0.05, so the distribution is Normal. (Abraham. B, 1983)

[3] *Selected stations*

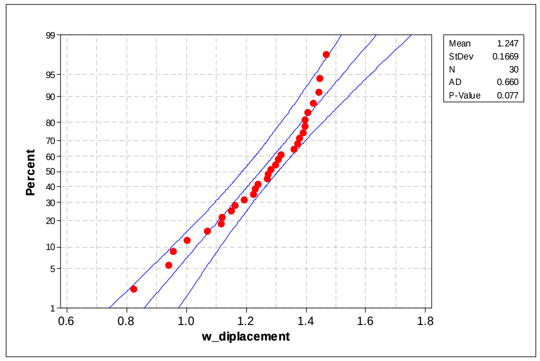

Figure 3. Probability Plot (P-P) diagram for the parameter of standard deviation in 30 log-normal distributions.

Thus, to calculate the confidence interval, the equation (6) can be applied:

$$\overline{X}_{\delta} - Z_{\frac{\alpha}{2}}.\delta_{\delta} < \mu_{\delta} < \overline{X}_{\delta} + Z_{\frac{\alpha}{2}}.\delta_{\delta} \quad (6)$$

$\overline{X}_{\delta}$: the mean of 30 data of standard deviation that is equal to 1.2472, δ_{δ} :the standard deviation of 30 data of standard deviation , that is equal to 0.1669 .

$$1.2472 - 1.96 \times 0.1669 < \mu_{\delta} < 1.2472 + 1.96 \times 0.1669 \rightarrow 0.9200 < \mu_{\delta} < 1.5734 \quad (7)$$

Therefore, the value of parameters related to standard deviation in the Log-Normal distribution is in the range of $[0.92, 1.57]$ with likelihood of 95%. *(Binder.D.A, 1983)*

Test of the obtained Log-Normal distribution and the determined range for the parameters with regard to Tabbas earthquake in IRAN

In order to study the Log-Normal distribution as well as the defined confidence interval of mean and std. derivation parameters, the records of the earthquake occurred in Tabbas, IRAN are applied. For this purpose, just like the abovementioned process, a concrete frame with shear wall were run in non-linear dynamic analysis in terms of the earthquake records of Tabbas, after accomplishing the mentioned analysis, the maximum displacement in stories was extracted from the output files. The proper distribution was selected by Kolmogorov-Smirnov Test. The obtained results were shown in table (4).

Table 4. Kolmogorov-Smirnov Test for log-normal distribution in a concrete frame with shear wall, based on Tabbas earthquake

displacement		
24	***N***	
4.496437048	***Mean***	***Normal Parameters(a,b)***
1.160661338	***Std. Deviation***	
0.125023215	***Absolute***	***Most Extreme Differences***
0.057057948	***Positive***	
-0.125023215	***Negative***	
0.612486166	***Kolmogorov-Smirnov Z***	
0.847330377	***Asymp. Sig. (2-tailed)***	

In view of the results in table (4), the value of Asymp.sig (2-tailed) parameter that is the Z statistic, is near to number one, thus the maximum displacement in stories of the frame in Tabbas earthquake are conformable along with log-normal distribution, as well as the parameter of the mean (4.49) is in the range of $[4.29, 5.24]$, and the parameter of standard deviation 1.16 is in the range of $[0.92, 1.57]$. Consequently, based on this fact it is revealed that the accuracy of the distribution function and the range of the parameters of mean and std. derivation.

Validation of Log-Normal Distribution Function Resulted From Tabbas Earthquake By Outputs Of IDARC Software

In order to study the validation of the resulted Log-Normal function from Tabbas earthquake, it should be compared the obtained output from Log-Normal function, with the output resulted from IDARC Software. For this purpose, the values of the maximum displacement in stories with Log-Normal distribution should be determined based on Tabbas earthquake .these values were calculated for the frame under records of 0.1g to 1.1 g acceleration (0.10g, 0.15g, … , 1.05g, 1.10g).

In figure (4), the output of the software (observational data) are placed on the horizontal axis, and the outputs resulted from Log-Normal distribution function (calculative data) are placed on the vertical axis. In figure (4), R-squared coefficient are 0.90 (R^2=0.90) and in linear-equation, coefficient of x are 0.87. This fact indicated that the calculated data resulted from Log-Normal distribution are conformable along with output data from IDARC software.[4]

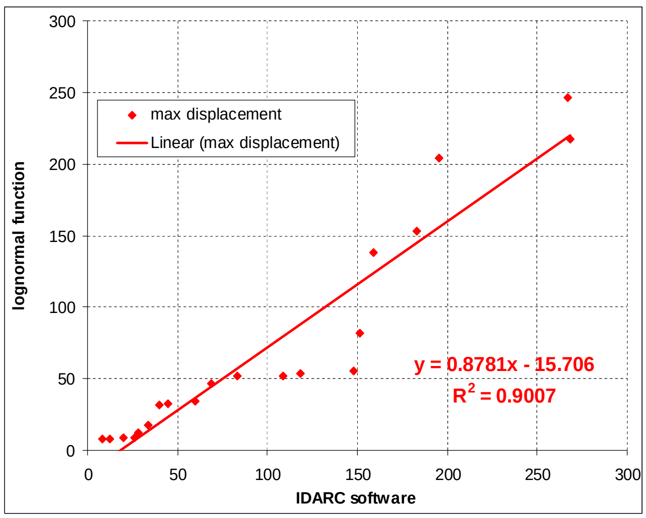

Figure 4. Comparing The Obtained results from Log-Normal distribution using outputs of IDARC Software, based on index of maximum displacement in stories

Conclution and Suggestions

- In view of the fact that in order to evaluate the vulnerability, the analysis of the concrete frame according to all the records throughout the worldwide, is a very hard and even an impossible work, so by determining the statistic distribution functions, the vulnerability of the concrete frames can be easily evaluated, without doing time-consumption and tiresome activity of nonlinear dynamic analysis of the frames.
- In order to evaluate the accuracy of the distribution and the range of the parameters, Tabbas earthquake records were applied. It was observed that the maximum displacement in stories is conformable along with the Log-Normal distribution and the relevant parameters including mean and standard deviation were included in the mentioned range.
- In *a concrete frame with shear wall and with 4–stories and 4-bays*, in an earthquake record with increasing acceleration, the maximum displacement in stories are conformable along with Log-Normal distribution and its parameters including mean and standard deviation are placed in the range of $[4.29,5.24]$ and $[0.92,1.57]$ with likelihood of 95%, respectively.
- The fulfilled research can be evaluated on the basis of determining the proper distribution function for the index of damage in the frames with several stories and different bays, besides the effects of the elevation and the number of bays can be studied based on the determined distribution.

[4] *The value of R^2 and coefficient of x are always within the range of 0 and 1. The more* conformable along with *these values to 1, the nearer the calculated data to the observational data.*

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