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fragility curves for steel moment frame with welded flange plate connection

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Abstract

The importance of evaluating the performance of structures against earthquakes is not hidden from anyone. It is important to have an overview of the resistance level of the structure to achieve a safe and economical design against the potential input forces. Therefore, a lot of research is always done in this area in different ways.

This article contains the method and results of the study of seismic vulnerability for WFP connection which is widely used and pre-approved connection for steel moment frames that Has been introduced in the tenth section of the Iranian building code. The purpose is to draw the fragility curve using numerical methods.

Due to the fact that this connection is pre-approved just for medium moment frames, it is necessary to check its reliability if want to use it in a special moment frame. The probability of structural damage caused by seismic force can be presented as a function of ground motion characteristics and various design parameters Using fragility curves. In this study, seven records of earthquake accelerograms were used for incremental nonlinear dynamic analysis (IDA) those most consistent with the site intended for this structure.

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Keywords: Fragility curves, incremental nonlinear dynamic analysis, pre-validated connections

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1-Introduction

Earthquake is one of the natural and destructive phenomena that always threatens the safety of buildings and the lives of their inhabitants in more parts of the world. For this reason, reducing the amount of damage caused by this phenomenon at the lowest cost has always been the goal of many types of research by researchers and scientists in earthquake and structural engineering.

after the Kobe earthquake (1995) which was associated with collapse and unforeseen damage to structures and also the frequency of brittle failure of welded joints of steel moment frame buildings in the Northridge earthquake (1994), the adequacy of the design and execution processes doubted

It raised the importance of assessing the likelihood of collapse and the extent of damage to existing buildings against future earthquakes. Then Extensive research was done on the strength and ductility of steel beam-to-column joints. A wide range of these studies focused on estimating the moment-curvature relationship and determining the force capacity and deformation of joints. Steel moment resisting frames with their flexible behavior and the possibility of creating wide and large architectural spaces have many applications in the design of buildings.

The performance of the joints in these frames includes the transfer of shear force due to gravity and the transfer of flexural moment due to lateral forces between the beam and the column.

In addition, the moment-rotation behavior of moment resistance connections is a very important factor in determining the overall behavior of the frame and therefore plays an important role in the absorption and dissipation of energy due to seismic excitation. In order to facilitate and standardize the design of special and medium moment resistance frame joints, a number of joints have been introduced in a pre-approved manner in Section 10 of the Iranian code. so that there is no need for independent testing in each project.

The requirements of these joints are determined and specified in such a way that to are capable of withstanding nonlinear deformations for the purpose of controlled collapse. This goal is achieved either by weakening the beam or by strengthening the joint to form a plastic hinge in the beam area.

One of the most common pre-approved welded connections in Iranian code is the welded flange plate (WFP) connection. Section 10th of the Iranian code has limited its use to medium and ordinary moment resistance frames. This connection is the only pre-approved connection in Iran that does not exist in AISC 358 standard. The bottom and top reinforcing plates are connected to the column flange by full groove welding with full penetration and to the beam flange by corner welding. These plates are responsible for tolerating moments on the column. Usually, the bottom plates are welded to the column in the factory. Therefore, the possibility of obtaining a groove weld with $\phi = 1$ is expected for it. But the top plate is welded to the column on the site and it is better to use a reduced factor of 0.75 or 0.85 for this weld. As a result, to ensure the required dimension and length of the weld, the top plate needs to be increased in width at the connection to the column, so, the top plate becomes a trapezoid or a cow head shape.

In summary, the process of studying the vulnerability of welded connections of steel moment frames in this article is as follows: Time history records related to the project area are selected. Records are scaled on different levels. The frame is modeled in ETABS software., Dynamic analysis of nonlinear time history is performed on the frame using earthquake records. Shears of the target columns are noted as the output of the frame analysis. The finite element model is simulated in ABAQUS software. Shear forces are applied in incremental steps to the finite element model. Maximum of time history drift for each connection in an earthquake is taken For all analyzes, with 0.1g incremental steps. Then IDA curve of connections based on maximum spectral acceleration and the connection rotation is plotted for all records.

2-background research

The production of fragility curves began in 1980 with the construction of nuclear facilities. Then, these curves were slightly developed by Kercher and Martin in 1993. These curves were computationally simple to some extent rudimentary and were prepared only experimentally with the help of engineering judgment. These curves were used to estimate the seismic damage of buildings. It can be said that after the Northridge earthquake (1994) more attention was paid to estimating the extent of structural damage. In 1994, the ATC-13 criteria for wooden structures, steel bending frames, and reinforced concrete (40 structures) were used to plot the brittle curves of structures in California. Ananus et al. Conducted further studies in 1995 based on the load distribution in the ATC and proposed a new model of the fragility curve. To date, many researchers around the world have done a lot of research on this subject.

3-Validation check

Validation in Abaqus means accurate modeling of a laboratory model in the finite element environment of Abaqus and its analysis and obtaining results similar to laboratory results.

Generally, to start these works, you choose a model similar to what you have in mind in terms of geometry, loading, etc., study the laboratory test paper of that model, and then create the model based on the Abaqus training section methods.

Therefore, by comparing the results of the tested model with the model simulated in Abaqus, the correctness of the modeling method is confirmed. In this research, the model made by Jahanbakhshi, Fanai, and Rezaian was used as a reference sample to verify the accuracy of finite element modeling results with a laboratory model. The desired model consists of a connection node and half of the beam span and two halves of the column height. And the loading was carried out in accordance with the regulations of SAC. Figure 1 shows the proper matching of the load-displacement diagrams of the laboratory sample and the finite elements

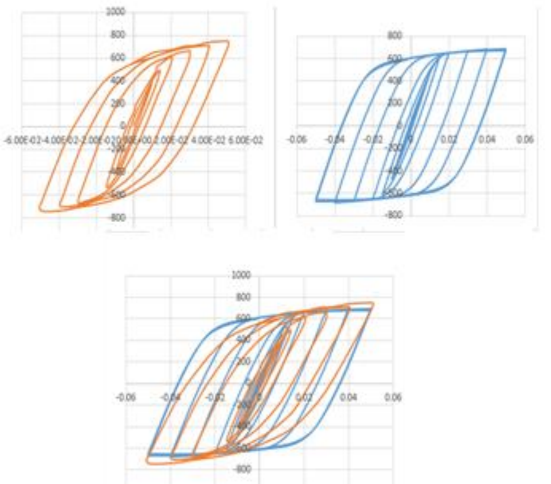

Figure 1 - Matching the hysteresis curve resulting from the modeling with the hysteresis curve of the article

4-Research Methods

According to the studies conducted after the Northridge and Kobe earthquakes, it can be said that velocity in near-field earthquakes and acceleration in far-field earthquakes are the controlling parameters. here the records of far-field earthquakes have been used because, in this research, the acceleration criterion has been studied.

Choosing the right accelerograms is one of the most important steps in nonlinear analysis. Because the nonlinear responses of the structure are highly dependent on the selected acceleration. For this reason, the selected earthquakes should have the same characteristics as the probable earthquake at the site under study. These specifications include the following: Magnitude, Distance, Fault Mechanism, Soil/Rock Type and Directivity.

These records were selected from the record tables suggested by FEMA365 in research work And downloaded from the "peer ground motion database". The names of these earthquakes can be seen in the table.

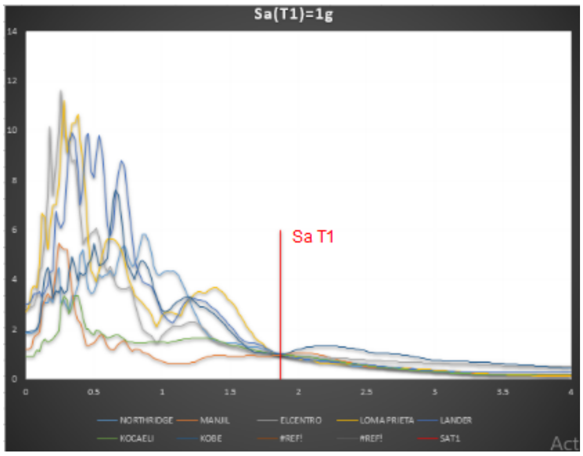

Figure 2- Earthquake spectra in the scaled mode of spectral acceleration equal to one

In this research, the spectral acceleration in the first period of structure Sa (T1) is used as the intensity parameter and incremental dynamic analysis (IDA) is done. The response spectra of selected earthquakes are scaled in terms of spectral acceleration. For this purpose, the value of the spectrum at the period of the structure (T1) is specified and by dividing the whole spectrum by this number, the amount of spectral acceleration at the time of the main period of the structure will be equal to one. Given that an incremental step for incremental dynamic analysis is selected equal to 0.1, it is easy to multiply the existing range by 0.1 to 0.9 to obtain the spectra required for the analysis. This procedure was performed for each of the 7 selected earthquakes. So in the end, there were 70 earthquakes that can use to do the analysis.

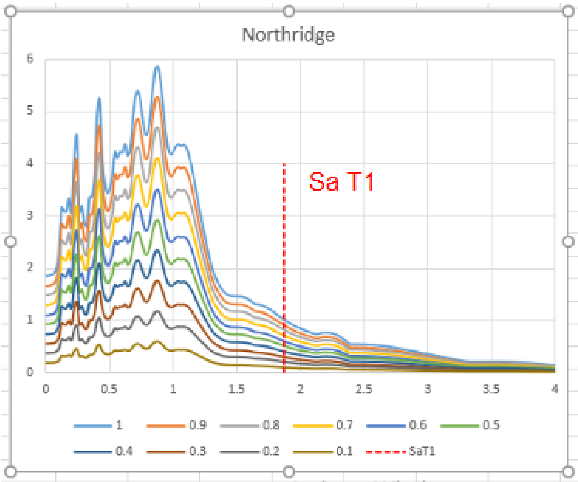

Figure 3-Northridge earthquake spectra in scale mode with step 0.1

5-Structural model

For modeling the frame in Etbas software, all the rules and restrictions related to the design of beams, columns, and pre-approved connections have been observed in accordance with the tenth section of the Iranian building code. Gravitational loads on the structure are in accordance with the sixth section of Iranian building code. Lateral loads on the structure are calculated according to the Iranian 2800 standard. The project site has been assumed as a high-level seismic risk area. The soil is assumed as type two soil. The structure is residential.

The research variables are shear and displacement, which are examined and measured as follows: The shear force is taken from Etbas software under nonlinear dynamic analysis. The shear force extracted from Etabs software is applied to the finite element model in Abaqus finite element software. The maximum displacement is specified at the top point of the column in Abacus software.

The structural model is a 2D 10-story bending frame with three spans of different lengths. Beams and a middle column on the second floor and a beam and a corner column on the eighth floor will be used for design. In this structure, box sections for columns and I-shaped sections for beams are used. In order to investigate the ductility of the types of connections expressed in each step, after performing the analysis on the 2D frame, the amount of shear is extracted from the software by applying the selected records.

6-Incremental dynamic analysis (IDA)

Incremental dynamic analysis (IDA) is a parametric analysis method That is used in several different forms to estimate more thoroughly structural performance under seismic loads.

It involves subjecting a structural model to one (or more) ground motion record(s), each scaled to multiple levels of intensity, thus producing one (or more) curve(s) of response parameterized versus intensity level. [1]

magnitude of the earthquakes measured by IM. IDA curves are plotted to plot damage magnitude (DM) against one or more severity measures (IM) based on two or more dimensions independent of IM. In this method, the maximum amount of acceleration is increasingly scaled from a very small value, during which the response of the structure is elastic and gradually increases until we reach a limit point after the surrender. In this case, the maximum values of the base shear versus the maximum displacement after each analysis are plotted, which is called the pushover dynamic diagram or IDA push curve.

6-1--Drawing IDA curves

After obtaining the change history at the Up Column point, the most displacement is picked, so there is maximum displacement per spectral acceleration; By obtaining the maximum displacement rate can draw the IDA curve. The following tables show the maximum rate of change in the column's up-point for the spectral acceleration of each model of connection, respectively.

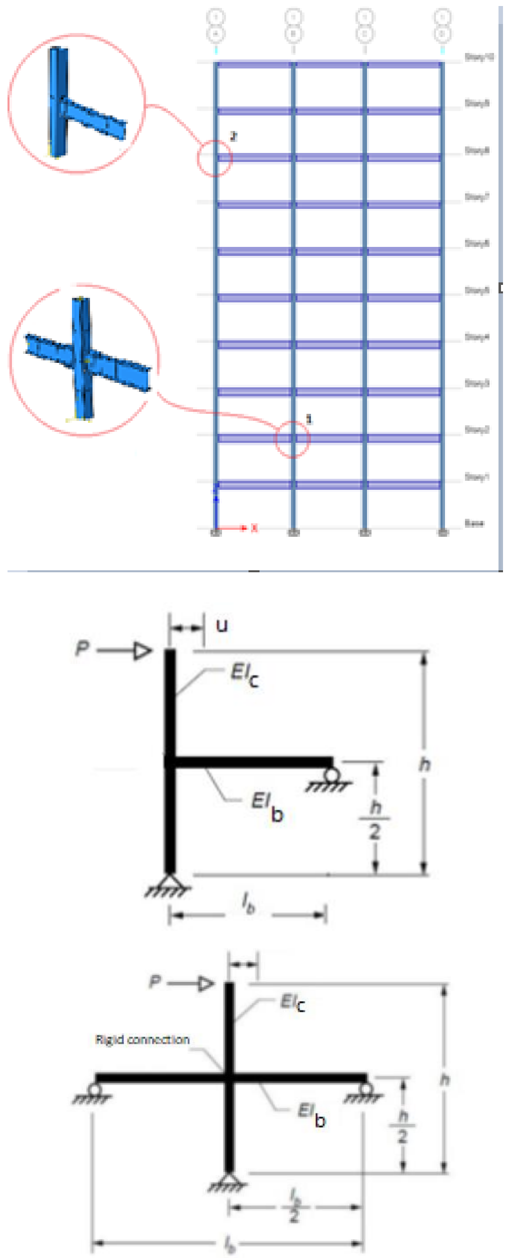

Figure 4: Force application point and boundary conditions

6-2-Building performance levels

The level of performance of the whole building is defined in terms of the level of performance of its structural and non-structural components. The different levels of performance of the building are: Operational Performance (OP), Immediate Occupancy Performance (IO), Life Safety (LS) and Collapse Prevention Performance (CP).

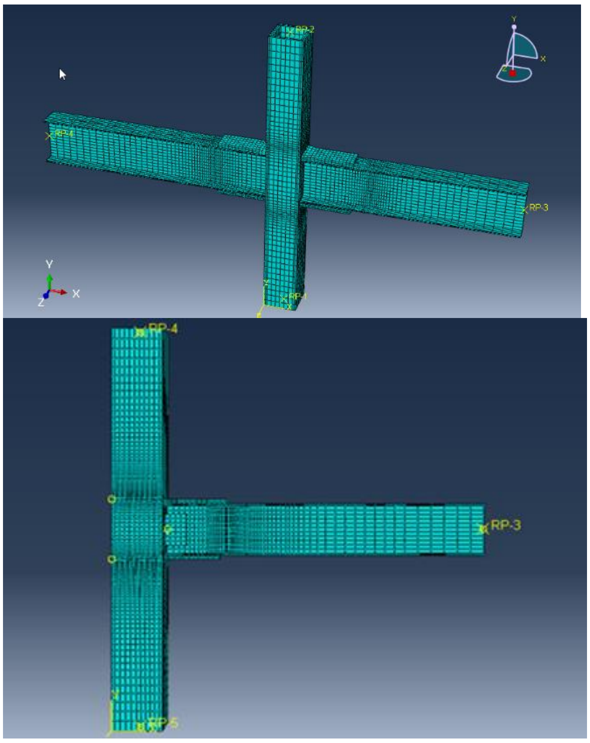

Figure 5: Meshed Model in ABAQUSE

6-3-Failure curve and its requirements

here the Numerical concepts and standard deviations are described to investigate and plot pre-confirmed connection failure curves.

Definition of arithmetic criterion, variance and standard criterion deviation:

In mathematics and statistics, the arithmetic mean is the sum of a collection of numbers divided by the count of numbers in the collection.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} X_i = \frac{1}{n}(x_1 + \cdots + x_n)$$

Which is used for a random example with n members of a statistical community. The mean of the main population n is generally defined as follows:

$$\mu_x = \frac{\sum_{i=1}^{n} X_i}{N}$$

Where N is the total number of members in the community.

In probability theory and statistics, variance is the expectation of the squared deviation of a random variable from its population mean or sample mean. Variance is a measure of dispersion, meaning it is a measure of how far a set of numbers is spread out from their average value.

$$\sigma_x^2 = \frac{\sum (X_i - \mu_x)^2}{N}$$

The above expression is known as variance and is denoted by the symbol σ^2

In statistics, the standard deviation is a measure of the amount of variation or dispersion of a set of values. A low standard deviation indicates that the values tend to be close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the values are spread out over a wider range.

The standard deviation is defined as follows.

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \mu_x)^2}{N}}$$

6-4-Function of normal log distribution

A random variable x has logarithmic normal distribution functions (or normal log distribution), if the variable Y = ln (X) has a normal distribution, then the probability density function of variable X is as follows:

$$f_x(x) = \frac{1}{\sqrt{2\pi\xi x}} \exp\left[-\frac{1}{2}\left(\frac{\ln x - \lambda}{\xi}\right)^2\right].$$

$$0 \le x \le \infty \qquad (11)$$

Where $\xi = \sqrt{var(\ln(x))}$ *and* $\lambda = \ln(X)$, which are the mean and standard deviation of the variable LN (X), are the distribution parameters, respectively.

6-5-LOGNORM.DIST function in Excel software

The Excel software calculates the value of the normal logarithm distribution density or the cumulative probability based on the normal logarithm utilization function (the LOGNORM.DIST function) or a value of the distribution (x value) and the normal logarithm distribution service (mean and standard deviation). The shape of this function is as follows:

LOGNORM.DIST (value, mean, standard deviation, cumulative or normal)

Here the parameters of this function are described:

Value: is a number that we want to get the cumulative probability value based on the normal logarithm distribution

Mean: The first parameter of the logarithm distribution is normal (a numerical value).

Standard deviation: The second parameter of the normal logarithm distribution, which is equal to the standard deviation (a numerical value).

Cumulative or Normal: A logical value for determining whether you want the cumulative probability value to be obtained or only the density value to be calculated. If this input is set to zero (False), the density value, and if it is set to one (True), then the cumulative probability value will be calculated.

After that, the results that the function returns are:

The LOGNORM.DIST function returns the value of the normal logarithm distribution density or the cumulative probability for the normal logarithm distribution function with defined parameters

The data tables obtained from the normal log distribution of IDA curves are given below.

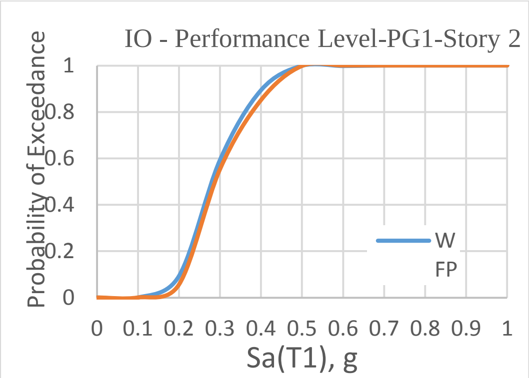

Figure 6- Comparison of fragility curves of WFP and WUF-W junctions in story 2

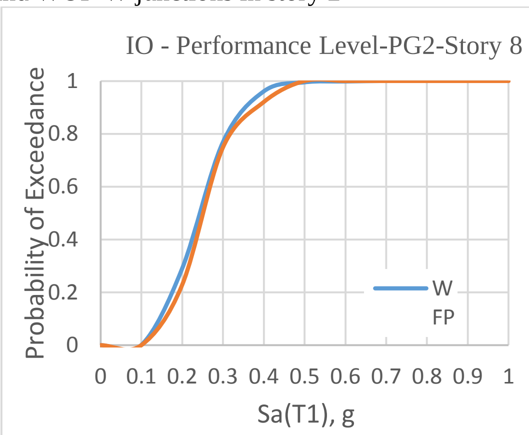

Figure 7- Comparison of fragility curves of WFP and WUF-W junctions in floor 2

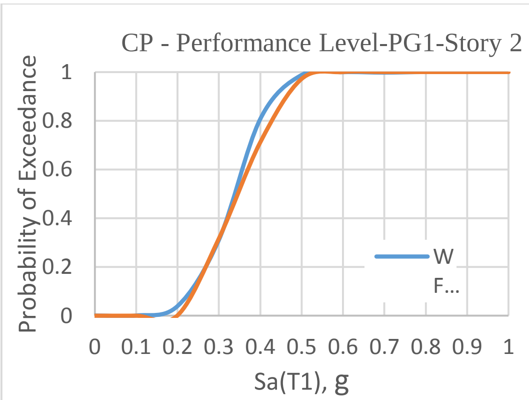

Figure 8- Comparison of fragility curves of WFP and WUF-W junctions in floor 8

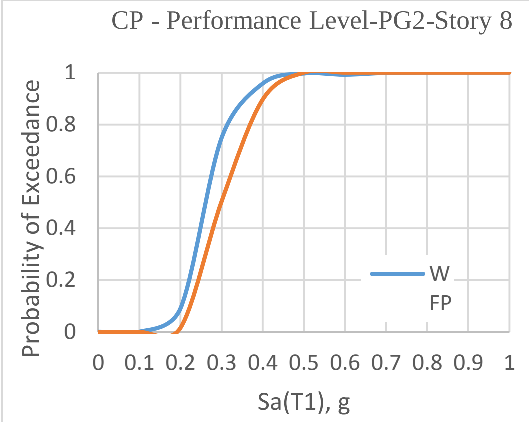

Figure 9- Comparison of fragility curves of WFP and WUF-W junctions in floor 8

7-Discussion on the accuracy of IDA results

The most important issue in assessing the accuracy of this method is if the average value of responses (or any other statistical value) obtained using the Earthquake Scale Records can be the same as the actual values obtained from real earthquakes?

Although a large amount of research is devoted to this, it is difficult to answer this question due to the limitation of seismic records that have equal IM.

In general, the answer to this question depends a lot on the structure, DM and IM values, and the population of records we use. However, the answers obtained from this method can be a piece of good evidence for the correctness of the hypotheses. For example, a comparison of studies that considered the value of the DM parameter for rotation, and the value of the IM parameter to be PGA or Sa (T1), shows that Sa (T1) shows less scatter in the range of DM values and it can be concluded that the spectral acceleration parameter in the first mode of the structure (Sa) T1 is a more appropriate parameter.

The data tables from the normal log distribution of IDA curves are presented in table 1 to 4.

8-The overall result

Fragility curves are undoubtedly one of the most useful and widely used tools for determining the probability of earthquake vulnerability. In this study, seismic fragility curves for two joints of the second and eighth floors of a steel bending frame were investigated.

Failure criteria were selected based on two levels of " Immediate Occupancy Performance " (IO) and " life safety " (LS).

The curves were calculated and plotted based on the effect of 7 different earthquake records that are as similar as possible to the type of soil and other

Table 1 - IDA curve normal log distribution data for IO performance level of second floor

Data for IO Performance Level story2

Earthquake	SaT1 (Sorted)	ln(SaT1)
kobe	0.241	-1.422958
Kocaeli	0.289	-1.241329
Landers	0.323	-1.130103
elcentro	0.362	-1.016111
loma	0.321	-1.136314
Manjil	0.319	-1.142564
Northridge	0.401	-0.913794

Mean (μ)	-1.143310449
Standard Deviation (σ)	0.149710194

Sa(T1)	ln(SaT1)	$\varphi\left(\frac{X-\mu}{\sigma}\right)$
0.1	-2.3026	4.83743E-15
0.2	-1.6094	0.000924313
0.3	-1.204	0.342665781
0.4	-0.9163	0.935290187
0.5	-0.6931	0.998680358
0.6	-0.5108	0.999988039
0.7	-0.3567	0.999999926
0.8	-0.2231	1
0.9	-0.1054	1
1.0	0	1

Table 2 - IDA curve normal log distribution data for CP performance level of second floor

Data for CP Performance Level story2

Earthquake	SaT1 (Sorted)	ln(SaT1)
kobe	0.33	-1.108663
Kocaeli	0.442	-0.816445
Landers	0.419	-0.869884
elcentro	0.491	-0.711311
loma	0.412	-0.886732
Manjil	0.414	-0.881889
Northridge	0.483	-0.727739

Mean (μ)	-0.857523342
Standard Deviation (σ)	0.122229322

Sa(T1)	ln(SaT1)	$\varphi\left(\frac{X-\mu}{\sigma}\right)$
0.1	-2.3026	1.4925E-32
0.2	-1.6094	3.83354E-10
0.3	-1.204	0.002295434
0.4	-0.9163	0.315330686
0.5	-0.6931	0.91065795
0.6	-0.5108	0.997719115
0.7	-0.3567	0.999979128
0.8	-0.2231	0.999999895
0.9	-0.1054	1
1.0	0	1

Table 3- IDA curve normal log distribution data for IO performance level of 8th floor

Data for IO Performance Level story8

Earthquake	SaT1 (Sorted)	ln(SaT1)
kobe	0.33	-1.108663
Kocaeli	0.21	-1.560648
Landers	0.23	-1.469676
elcentro	0.22	-1.514128
loma	0.412	-0.886732
Manjil	0.17	-1.771957
Northridge	0.21	-1.560648

Mean (μ)	-1.410350085
Standard Deviation (σ)	0.281683429

Sa(T1)	ln(SaT1)	$\varphi\left(\frac{X-\mu}{\sigma}\right)$
0.1	-2.3026	0.000768753
0.2	-1.6094	0.239852029
0.3	-1.204	0.768116112
0.4	-0.9163	0.960280676
0.5	-0.6931	0.994553784
0.6	-0.5108	0.99929693
0.7	-0.3567	0.999908222
0.8	-0.2231	0.999987494
0.9	-0.1054	0.999998196
1.0	0	0.999999723

Table 4- IDA curve normal log distribution data for CP performance level of 8th floor

Data for CP Performance Level story8

Earthquake	SaT1 (Sorted)	ln(SaT1)
kobe	0.23	-1.469676
Kocaeli	0.271	-1.305636
Landers	0.245	-1.406497
elcentro	0.275	-1.290984
loma	0.23	-1.469676
Manjil	0.46	-0.776529
Northridge	0.24	-1.427116

Mean (μ)	-1.306587828
Standard Deviation (σ)	0.226435557

Sa(T1)	ln(SaT1)	$\varphi\left(\frac{X-\mu}{\sigma}\right)$
0.1	-2.3026	5.44781E-06
0.2	-1.6094	0.090535124
0.3	-1.204	0.674788776
0.4	-0.9163	0.957615054
0.5	-0.6931	0.996626883
0.6	-0.5108	0.999779542
0.7	-0.3567	0.999986361
0.8	-0.2231	0.999999144
0.9	-0.1054	0.999999944
1.0	0	0.999999996

conditions of the site. These curves can be used to estimate the overall seismic vulnerability.

The results of IDA analysis in this study and similar studies indicate that this method of analysis can be very effective in evaluating the seismic performance of structures. Therefore, despite the limitations of this method, it seems to can replace the usual and approximate methods such as load analysis due to its strengths. This method considers the behavior of materials nonlinearly and has a dynamic nature. Therefore, compared to static methods such as linear static analysis (pushover) and other linear methods such as dynamic linear spectral analysis can be the most accurate method of estimating structural behavior.

The following results can be deduced from the obtained failure curves :The presented curves show that in general, the more the curves move to the left, it means that the probability of fragility increases.

That is, the probability of the structure passing the low failure state occurs at lower spectral acceleration values . And occurs in moderate, extensive, and general failure modes at higher values of spectral acceleration, respectively .In other words, with increasing Sa, fragility increases.

By increasing the intensity parameter or seismic requirement, the probability of exceeding a certain limit state will be higher. In other words, according to fragility curves, in earthquakes with different return periods, the probability of exceeding a certain limit state of failure for a structure or part It determined. Therefore, fragility curves are undoubtedly one of the most useful and widely used tools to determine the probability of earthquake vulnerability.

In this paper, two joints of steel bending frames were investigated, and brittleness curves were prepared for both joints. According to the fragility diagram of the joints, the results showed that the behavior of the two joints is somewhat similar. Both connections performed satisfactorily Also, the performance of the WUF-W connection was somewhat better than the WFP connection. In some cases, especially at high seismic intensities, the WFP connection shows a slight increase in damage. And it has less reliability than connecting a steel bending frame using a WUF-W connection.

9-Acknowledgments

finally, this part is the only section in that I can say what my heart wants to say. I appreciate my wife for revival me. my eyes became able to see after The first time I saw her.

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