SEISMIC FRAGILITY CURVES FOR INDUSTRIAL STEEL BUILDINGS

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1. ABSTRACT

The reliable assessment of structural damage after an earthquake event is essential to organize the emergency response and to facilitate the structural and economic losses. Fragility curves are basic components in the process of earthquake loss estimation. They give the probability of exceeding a number of damage states as a function of an intensity measures (IM) such as ground motion. In this paper, fragility curves were developed for steel frames in industrial buildings. Those structures have high impact for the financial prosperity of a region. Fragility curves for those steel structures are not common met in civil engineering literature. Non – linear dynamic analysis have been performed for a 3D steel frame and statistical process of the results in order to obtain the fragility curves for five different damage stages (ds). The damage stages were the three level of inter-story drift according to the literature and additional two more stages which are the yielding of diagonal member of brace and the buckling of frame column.

Keywords: seismic fragility curves, steel frames, earthquake loss estimation

2. INTRODUCTION

The methods to estimate seismic fragility functions can be grouped in three categories. The first is empirical, the second analytical, and last one expert opinion methods. However, efforts, which combine two of these approaches, are also presented. Empirical methods perform regression analysis of observed seismic performance with seismic excitation. The work by Wesson et al. (2004) employs a large database of insurance claims from the 1994 Northridge earthquake, a rare occurrence in the public domain. The GEM Vulnerability Consortium, (GVC), (2012), contributes to empirical methods since try to harmonize a variety of damage scales and create one that can be applied globally. US Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER) project offers another approach to empirical vulnerability. In this project a statistical calculation determining probable past conditions of whole-earthquake fatality and economic losses, applying parametric vulnerability functions to estimates of number of people shaken at various levels of earthquakes intensity.

In analytical methods, numerical calculations in order to estimate damage or loss are used. A lot of work on analytical approaches was done, one description is presented in ATC-58 (ATC 2012) which is the most recent and shows the tendency that the relative area of research is imprinted to the guidelines. In analytical approaches details such as the construction material, lateral force resisting system, height category, occupancy category, the area of building and all structural and non-structural component are taken into consideration. Representative software that applies analytical approaches are HAZUS-MH, PACT (2012), EQRM (Robinson et al. 2006), ELER (2010), CAPRA (2010) and SELENA (Molina et al. 2010). Those methods compared with nonlinear dynamic analyses, considered as reference method. Hybrid methods combine statistical data with appropriately processed results from nonlinear dynamic or static analyses that permit interpolation of statistical data to PGAs and/or spectral displacements for which no data is available. Statistical procedures for contracting earthquake damage fragility functions are developing by Lallemant et al (2015). Noh et al (2012) developed fragility functions derived from the wavelet-based damage sensitive feature *(DSF)* .Güneyisi, (2012) investigated the seismic reliability of three-storey and eight-storey steel moment resisting frames before and after retrofitting with buckling restrained braces (BRBs) in terms of seismic fragility and risk analysis. He developed fragility curves from the natural ground motions with low and high a/v ratio, (peak ground acceleration divided by the peak ground velocity).

In this paper seismic fragility curves of industrial steel buildings are developed.

3. THEORETICAL BACKROUND & CODES FOR DEVELOPING FRAGILITY CURVES

The probability of structure being in or exceeding a given damage state is modeled as a cumulative lognormal distribution. For structural damage, given the ground acceleration, a_g, the probability of being in or exceeding a damage state, ds, is modeled as:

$$P\left[ds|a_g\right]=\Phi\left[\frac{1}{\sigma_{ds}}\ln\left(\frac{a_g}{\overline{a}_{g,ds}}\right)\right] \qquad (1)$$

where:

$\overline{a}_{g,ds}$ is the median value of ground acceleration at which the building reaches the threshold of the damage state, d_s,

σ_{ds} is the standard deviation of the natural logarithm of ground acceleration of damage state, ds,

Φ is the standard normal cumulative distribution function.

The median value of ground acceleration, $\bar{a}_{g,ds}$ and the standard deviation of the natural logarithm of ground acceleration, σ_{ds}, are calculated through a number of dynamic analyses for different earthquakes of the building when it reaches at a given damage state, d_s. However, non-linear static procedures can be applied in order to calculate those parameters. Furthermore, fragility curves can be represented with other intensity measures such as spectral displacement or the earthquake intensity.

In this study the median value of spectral acceleration, $\bar{S}_{d,ds}$, and the standard deviation of the natural logarithm of spectral acceleration, σds, are calculated through a number of non-linear dynamic analyses for different earthquakes. The general procedure, followed in this study, is as showed in figure 1.

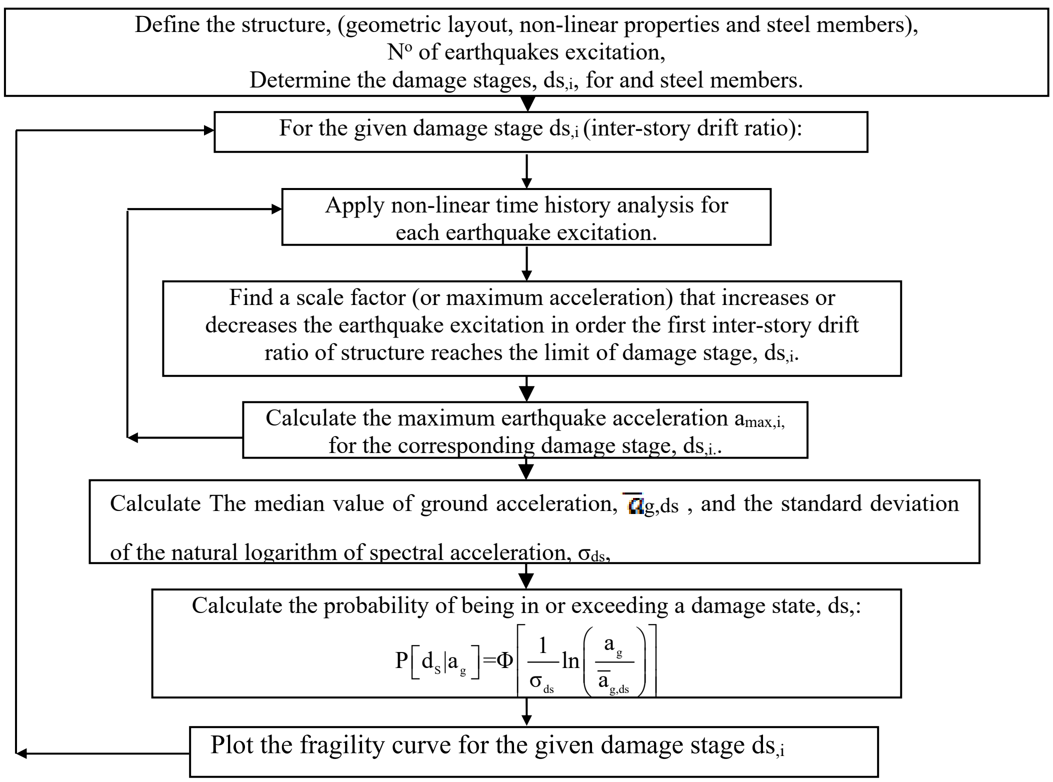

Fig. 1: Chart diagram procedure for fragility curve calculation.

4. FRAGILITY CURVES OF INDUSTRIAL STEEL BUILDING – NUMERICAL APPLICATION

The industrial steel model consists of one story building that is entirely made from structural steel, which is a typical industrial building. The building has three openings of 5 m in the y – axis, 20 m the roof opening and the height is 6m. The material, that was used, is structural steel S275. The columns on the edges of the building are HEB 600 and the middle ones are HEB 700. The primary steel beams vary from HEA 400 to HEA 900, the secondary steel beams vary from IPE 240 to IPE 300 and the diagonal rods are RHCF 200x100x6.3. The geometry layout and the member sections is shown in figure 2. All the vertical loads were applied on the beams as distributed loads. The dead loads are 5 kN /m while the live loads 15 kN /m. The building was designed according to Eurocode 2 and 3. For seismic action, the design spectrum of Eurocode 8 was used. The parameters for seismic action was a_g=0.36g, soil type B, response spectrum type 1. An assumption of the behavior factor equal to 3 was done for the structure. In order to calculate the fragility curve of the steel building ten earthquake excitations were used. The record characteristics of the earthquakes are shown in table 1. The inter-story drift ratio was chosen as a measure of damage states. Five damage states levels were determined. The first damage state level, $ds_{,1}$, is when the inter-story drift ratio is reach at 0,3%. The second and third damage state level, $ds_{,2}$, $ds_{,3}$, corresponds to the inter-story drift ratio of structure equal to 1% and 2% respectively. The fourth damage state $ds_{,4}$ is when the diagonal rods yield and fifth damage $ds_{,5}$ is when failure occurs due to column buckling.

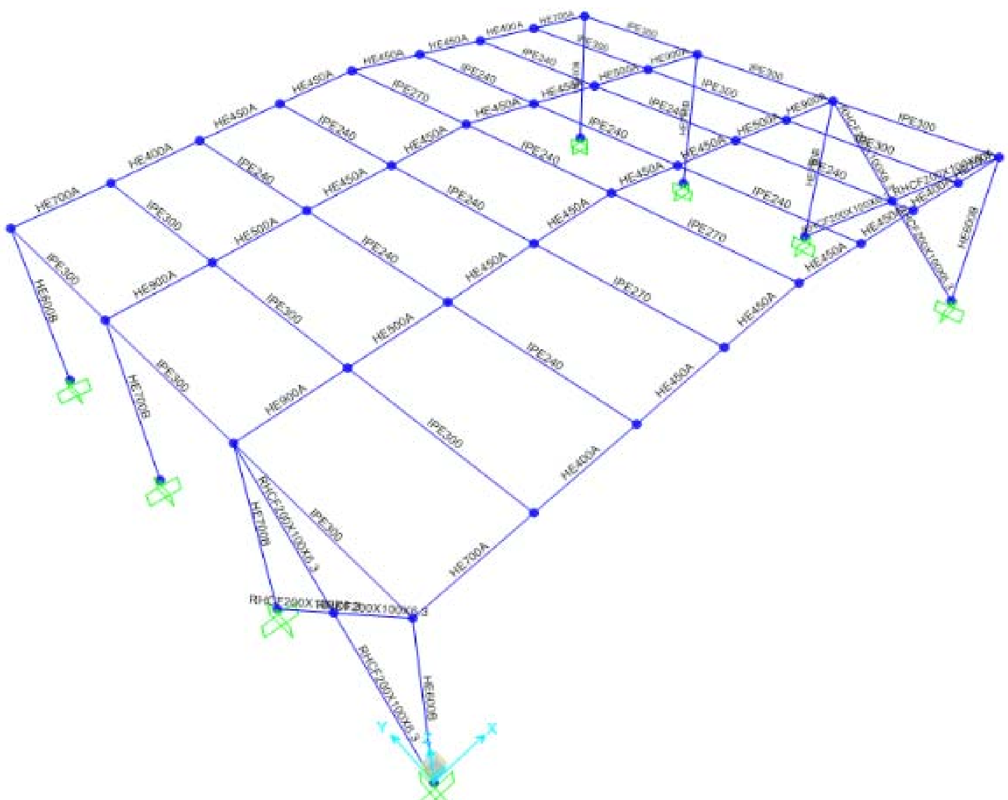

Fig. 2: The geometry layout of industrial steel building.

No.	Date	Record Name	Comp.	Station Name	PGA (g)
1	1980/06/09	Victoria, Mexico	N045	6604 Cerro Prieto	0.621
2	1992/04/25	Cape Mendocino	NS	89324 Rio Dell Overpass	0.549
3	1978/08/13	Santa Barbara	N048	283 Santa Barbara Courthouse	0.203

4	1978/08/13	Santa Barbara	N138	283 Santa Barbara Courthouse	0.102
5	1999/09/20	Chi-Chi, Taiwan	NS	TCU095	0.712
6	1994/01/17	Northridge	EW	90021 LA - N Westmoreland	0.401
7	1989/10/18	Loma Prieta	EW	58065 Saratoga - Aloha Ave	0.512
8	1992/06/28	Landers	NS	22170 Joshua Tree	0.284
9	1976/09/15	Friuli, Italy	EW	8014 Forgaria Cornino	0.26
10	1994/01/17	Northridge	NS	90019 San Gabriel - E. Gr. Ave.	0.256

Table 1: Recorded earthquake ground motions

Based on the procedure shown in figure 1 the fragility curves of the above industrial steel building for the 5 damage states were obtained both on the x – axis and the y - axis. After performing the dynamic analysis and including the values of fragility curve parameters, the fragility curves for both axes of the industrial steel building can be plotted as shown in figures 3 and 4.

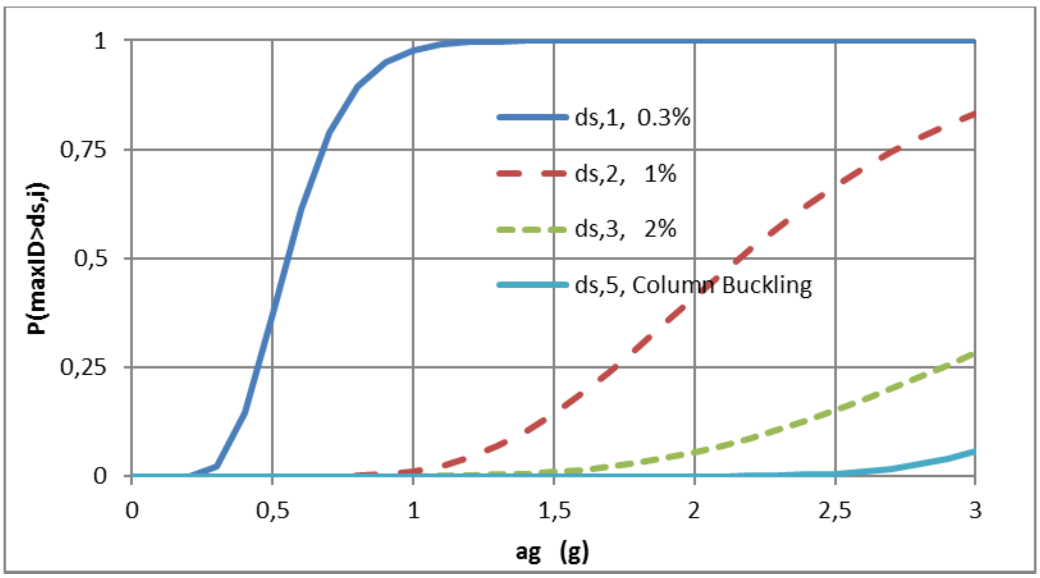

Fig. 3: Fragility curves of the industrial steel building on x-axis

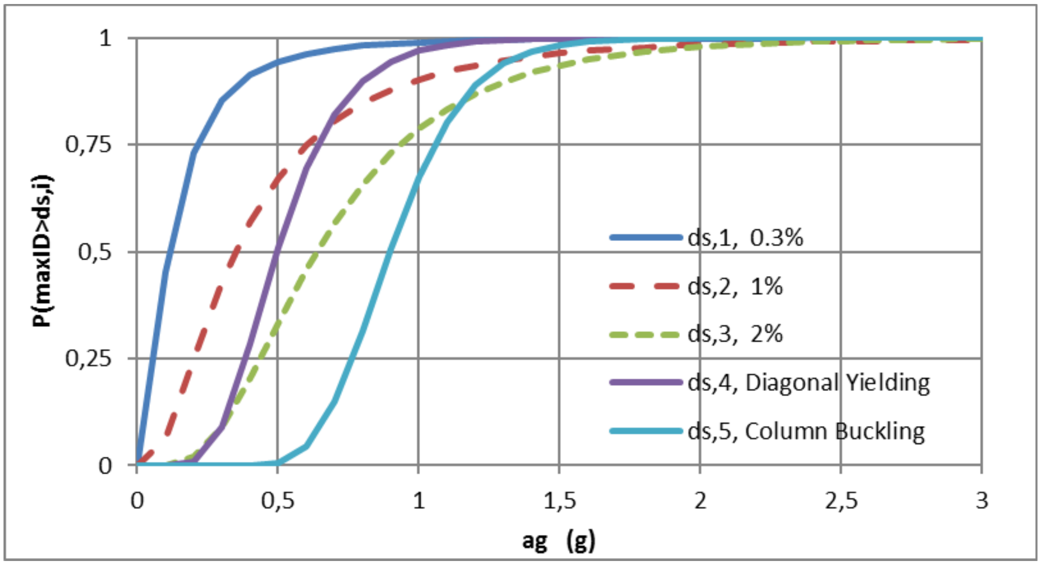

Fig. 4: Fragility curves of the industrial steel building on the y-axis

From the above figures (Fig.4 &5) it is observed that the diagonal yielding and column hinge in x direction are not critical damage states since in that direction the diagonal rods are not intended to work and the column power axis is parallel to x direction. Furthermore, the damage states 2 and 3 (1% & 2% respectively) in x direction have low possibility to occur comparing to the y direction that damage states 2 and 3 attain greater values of possibilities. In figure 4 a crosspoint is observed between ds2 (1%) and ds4 (diagonal yielding) at 0,6g which means the interstory drift is more critical to happen for values lower than 0,6g while the diagonal yielding is more critical to happen for values greater than 0,6g. Another crosspoint in figure 4 is observed between ds3 (2%) and ds5 (column buckling) at 1,2g which means the interstory drift is more critical to happen for values lower than 1,2g while the column buckling is more critical to happen for values greater than 1,2g.

5. CONCLUSIONS

Fragility curves are an essential tool, which direct deals with earthquake loss estimation. In this work fragility curves for industrial steel building, designed with current code and for the five damage stages were developed. The yielding of the diagonals and the buckling of columns were also taken into consideration as two additional damage stages. From the analyses results, the possibility values of each damage state can be shown for a specific peak ground acceleration value. Furthermore, crossover points from fragility curves show the limits for each critical damage state.

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ΚΑΜΠΥΛΕΣ ΣΕΙΣΜΙΚΗΣ ΤΡΩΤΟΤΗΤΑΣ ΒΙΟΜΗΧΑΝΙΚΩΝ ΜΕΤΑΛΛΙΚΩΝ ΚΤΙΡΙΩΝ

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ΠΕΡΙΛΗΨΗ

Η αξιόπιστη εκτίμηση των δομικών βλαβών μετά από ένα σεισμικό γεγονός είναι αναγκαία για την οργάνωση της έγκαιρης επέμβασης και για την αποτίμηση των δομικών και οικονομικών απωλειών. Οι καμπύλες σεισμικής τρωτότητας είναι βασικό εργαλείο στη διαδικασία εκτίμησης των σεισμικών βλαβών. Η καμπύλη τρωτότητας δίνει την πιθανότητα υπέρβασης μιας κατάστασης βλάβης συναρτήσει των μέτρων έντασης ενός σεισμού όπως για παράδειγμα η εδαφική σεισμική κίνηση ή επιτάχυνση ή το μέγεθος ή η ένταση του σεισμού. Στην παρούσα εργασία οι καμπύλες σεισμικής τρωτότητας που αναπτύχθηκαν αφορούν μεταλλικά πλαίσια για βιομηχανικά κτίρια. Αυτές οι κατασκευές έχουν μεγάλη επίδραση για την οικονομική ευημερία μιας περιοχής. Καμπύλες σεισμικής τρωτότητας για τον συγκεκριμένο τύπο κατασκευών δεν υπάρχουν στην υπάρχουσα βιβλιογραφία. Για τις ανάγκες της παρούσας εργασίας έγινε μη – γραμμική δυναμική ανάλυση ενός τρισδιάστατου μεταλλικού πλαισίου καθώς επίσης και στατιστική επεξεργασία των αποτελεσμάτων προκειμένου να ληφθούν οι καμπύλες σεισμικής τρωτότητας για πέντε διαφορετικές καταστάσεις βλαβών.

Λέξεις – Κλειδιά: Σεισμικές καμπύλες τρωτότητας, μεταλλικά πλαίσια, σεισμικές απώλειες