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Research Article

SEISMIC RISK ANALYSIS OF SHIRAZ, IRAN

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ABSTRACT
Occurring earthquake in the Iranian plateau is common, due to placing Iran on seismic belt and having a large number of faults. Iran stayed in the first 10 disaster-prone countries and is 6th seismic country in the world. Seismic belt sounded 90 percent of Iran area and caused the most human casualties, but the considerable point is that, a majority number of metropolises built on or beside the faults and are in risk. In this paper by using HAZUS method, amount of damage and loss of life calculated for each area separately.

Keywords: *Seismic Damage, Loss Assessment, HAZUS, Shiraz*

INTRODUCTION
Shiraz with a population of about one & half million people is one of the most densely populated metropolises of the Iran. In this region, there are many faults that Kazeroon fault, Zagros are the most important of them. Fars Province in the state and one of the most seismically active tectonic Zagros Rvd. shmar areas of the state's historical earthquake and the numerous devices, basement active faults, seismic sources and also strong reasons to continue event Neotectonics movement in the province, all show high seismic potential. From hence any attempt to accurately assess risk and prevent the damage caused by the earthquake is of great importance.
Population and area of existing building with respect to structure type are presented in Table 1 and 2, respectively. In this study, the city is divided into nine zones in order to obtain accurate results.

MATERIALS AND METHODS
Methodology
In this study, SELENA ver.6 software which work based on HAZUS method was used. Structures categorized based on their application and vital data were obtained from Iranian Statistics Society reports and GIS plans of Shiraz. Used method in this investigation is the newest standard which used in United Stated of America. As a result of data absence about not structural members, loss and damage of structural members were calculated.

Table 1: Scale of Population in Different Zones of the City (GIS Map of Shiraz City Block of Population, 2011-2012)

District	Population
1	66555
2	52601
3	56274
4	67358
5	40795
6	47629
7	52856
8	12981
9	31202
Total	428251

Table 2: Area of Existing Building (m^2) (GIS Map of Shiraz City, 2012-2013)

District	Structural Type		
	Masonry	**Steel**	**Concrete**
1	4778634	1464419	2939787
2	100536	1209715	286297
3	23228	1591851	342260
4	6961	1376010	3818571
5	16170	132305	414894
6	9829	236358	1520499
7	25380	1068107	414735
8	333	139285	539563
9	895	107152	192310

To determine soil type, standard spectrum method, based on IBC-2006 (International Building Code, 2006). Design code used. In this method ground motion divided into 4 parts by presented standard spectrum in IBC. Also in this spectrum acceleration must be calculated in 2 period, 0.3 second and 1 second.

$$Sa(T) = Sa_{0.3}\left(0.4 + \frac{T}{T_A}\right) \qquad T < T_A$$
$$Sa(T) = Sa_{0.3}T_A < \ T < T_{AV}$$
$$Sa(T) = \frac{Sa_{1.0}}{T}T_{AV} < \ T < T_{VD}$$
$$Sa(T) = \frac{Sa_{1.0}T_{VD}}{T^2}T_{VD} < \ T < 10\ s$$

Most of the structures designed and evaluated by using linear elastic method to ease, therefore structure response obtained based on linear elastic specifications. Capacity curve of structure is a simple, accurate and reasonable tool to predict non-linear response of structure to determine damage. Pushover cure has 3 control points, Design Capacity, Yield Capacity and Ultimate Capacity. These points presented in a figure 1.
Design Capacity demonstrates nominal strength of structure which defined by design code. Yield Capacity shows real lateral strength of structure by considering load reduction in designing, criteria consideration and actual strength of materials. Ultimate Capacity defines the maximum strength of structure in plastic mode (Multi-hazard Loss Estimation Methodology, 2003).

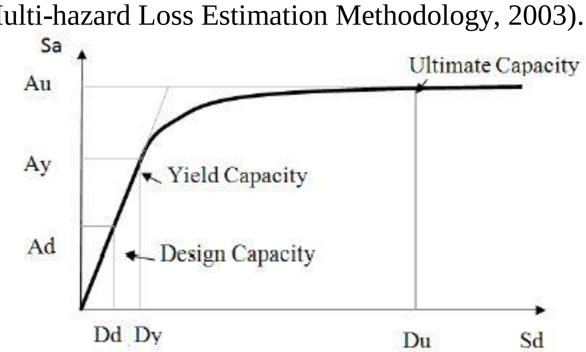

Figure 1: Pushover Curve of Structure

Pushover curve parameters considered based on presented tables by HAZUS for steel and concrete structures based on moderate code, and masonry buildings based on Low code. Also to get structure response modified acceleration response spectrum was used.

Table 3: Capacity Curve Parameters for the Design Moderate Code (Multi-Hazard Loss Estimation Methodology, 2003)

Building Type	Yield Capacity Point		Ultimate Capacity Point	
	Dy(in)	Ay(g)	Du(in)	Au(g)
S1L	0.31	0.125	5.5	0.375
S1M	0.89	0.078	10.65	0.234
S1H	2.33	0.049	20.96	0.147
S2L	0.31	0.2	3.76	0.4
S2M	1.21	0.167	9.7	0.333
S2H	3.87	0.127	23.24	0.254
S4L	0.19	0.16	2.59	0.36
S4M	0.55	0.133	4.91	0.3
S4H	1.74	0.102	11.76	0.228
C1L	0.2	0.125	3.52	0.357
C1M	0.58	0.104	6.91	0.312
C1H	1.01	0.049	9.05	0.147
C2L	0.24	0.2	3.6	0.5
C2M	0.52	0.67	5.19	0.417
C2H	1.47	0.127	11.02	0.317
URML				
URMM				

Table 4: Capacity Curve Parameters for the Design Low Code

Building Type	Yield Capacity Point		Ultimate Capacity Point	
	Dy(in)	Ay(g)	Du(in)	Au(g)
S1L	0.15	0.062	2.29	0.187
S1M	0.44	0.039	4.44	0.117
S1H	1.16	0.024	8.73	0.073
S2L	0.16	0.1	1.57	0.2
S2M	0.61	0.083	4.04	0.167
S2H	1.94	0.063	9.68	0.127
S4L	0.1	0.08	1.08	0.18
S4M	0.27	0.067	2.05	0.15
S4H	0.87	0.051	4.9	0.114
C1L	0.1	0.062	1.47	0.187
C1M	0.29	0.052	2.88	0.156
C1H	0.5	0.024	3.77	0.073
C2L	0.12	0.1	1.5	0.25
C2M	0.26	0.083	2.16	0.208
C2H	0.74	0.063	4.59	0.159
URML	0.24	0.2	2.4	0.4
URMM	0.27	0.111	1.81	0.222

Damage function defined as a semi-logarithmic fragility curve, which presented in figure 2. Based on this function damage levels categorized into 4 different levels, low, moderate, speared and full. Fragility curve parameters according to HAZUS for each structure type.

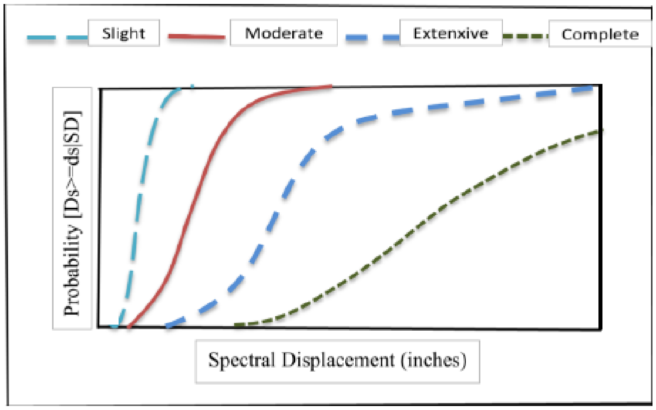

Figure 2: Fragility Curves (Multi-hazard Loss Estimation Methodology, 2003)

Each earthquake in addition to loss of life has economic damages such as structural and non-structural damages, damage of equipment, ways, airports and etc. economic damages based on damage type and in some cases by replacing building by its cost calculated. Losses evaluated according to damages. In weak earthquakes non-structural damages are determinant but in strong earthquakes structural damages play key role.

To calculate and prognosticate amount of damages 3 times considered as below.

1) 2 A.M when most of the people are in their houses.
2) 10 A.M when a majority number of people are at work, university and or schools.
3) 5 P.M whilst a large number of people are in way to return where they inhabit.

Population distribution of studied zone in different times based on HAZUS prepared in table 5.

Table 5: Population distribution of studied zone in different times based on HAZUS (Multi-Hazard Loss Estimation Methodology, 2003)

Distribution of People in Census Tract			
Occupancy	2 : 00 a.m.	10:00 a.m.	5:00 p.m.
Indoors			
Residential	(0.999)0.99(NRES)	(0.7)0.75(DRES)	(0.7)0.5(NRES)
Commercial	(0.999)0.02(COMW)	(0.999)0.98(COMW)+ (0.80)0.20(DRES)+ 0.8(Hotel)+ 0.8(Visit)	0.98[0.50(COMW)+ 0.1(NRES)+ 0.70(HOTEL)]
Educational		(0.90)0.80(GRAD)+ 0.8(COLLEGE)	(0.8)0.5(COLEGE)
Industrial	(0.999)0.1(INDW)	(0.90)0.80(INDW)	(0.90)0.50(INDW)
Hotels	0.999(HOTEL)	0.19(HOTEL)	0.299(HOTEL)
Outdoors			
Residential	(0.001)0.99(NRES)	(0.30)0.75(DRES)	(0.30)0.50(NRES)
Commercial	(0.001)0.02(COMW)	(0.01)0.98(COMW)+ (0.20)0.20(DRES)+ (0.20)(VISIT) + 0.50(1-PRFIL)0.05(pop)	0.02[0.50(COMW)+ 0.1(NRES)+ 0.70(HOTEL)+ 0.5(1-PRFIL) [0.05(POP)-1.0(COMM)]
Educational		(0.10)0.80(GRADE)+ 0.20(COLLEGE)	(0.20)0.50(COLLEGE)
Industrial	(0.001)0.10(INDW)	(0.1)0.80(INDW)	(0.1)0.50(INDW)
Hotels	0.001(Hotel)	0.01(HOTEL)	0.001(HOTEL)

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Considered application and habitation washed in six type where can include sub categories.
Applications are Residential, Commercial, Educational, Office, Health and Service.
Seismic risk analysis has various results. Variety in results and also different types of structures with divers application, caused error in results. To solve this problem FEMA (Improvement of nonlinear static seismic analysis procedures, 2005) define a ratio pronounced average damage. By this ratio damages in different zones and cities became comparable.
Analytical analysis of used software can perform by 3 different ways which are as follow:
1) Deterministic Analysis
2) Probabilistic Analysis
3) Analysis with real time data

Economic Loss

SELENA can also estimate the total amount of economic losses (in any input currency) due to structural damage in any geographical region.
Economic loss for building renovation (and for reconstruction, in the case of complete damage) is computed based on the following equation (Molina, D.H. Lang, C.D. Lindholm, F. Lingvall, 2010).

$$L_{eco}=C_r\sum_{i=1}^{N_{OT}}\sum_{J=1}^{N_{BT}}\sum_{K=1}^{N_{DS}}A_{i,j}P_{j,k}C_{i,j\,k}$$

Where N_{OT} is the number of occupation types, N_{BT} presents the number of building types and N_{DS} is the number of damage states. In this equation, C_r, is regional cost multiplier (currently is set to 1.0, but can have different values for each geographical region in order to take into account the geographic cost variations); $A_{i,j}$ is the area of building type *j* with type *i* occupancy (in m^2); $P_{j,k}$ is the damage probability of a structural damage type *k* (slight, moderate, extensive or complete) in the building type *j* and $C_{i,j,k}$ is the cost of renovation or reconstruction (per m^2) for structural damage *k* in building type *j* with *i* occupancy.

Human Loss - Casualties

The applied methodology for calculating the number of human casualties, basically, follows the HAZUS approach but is somewhat simplified using the formulas given by Coburn and Spence equation (Multi-hazard Loss Estimation Methodology, 2003):

$$K = K_s + K' + K_2$$

Where, K_s is the number of casualties due to structural damage, K' is the number of casualties due to non-structural damage and K_2 is the number of casualties due to follow-on hazards such as landslides, fires, etc.
Equation can also be modified such that the level of injury (severity) is considered:

$$K_i = K_{si} + K_i' + K_{2i}$$

Where *i* represents the level of severity, ranging from light injuries $(i=1)$, moderate injuries $(i=2)$, heavy injuries $(i=3)$ to death $(i=4)$.
A more detailed description of the severity levels is given in Table 3.
By using SELENA, the number of human losses (casualties) can be computed using two different methods:
1. Basic Methodology: Where detailed information on population distribution is not available or could not be inferred from available data.

2. HAZUS Methodology: Where detailed information on population distribution is available.

Considered occupancies in this study are consist of residential, commercial, sanitary, educational and services.

In order to consider several cases of occupancy which strongly depend on time of day (i.e., school occupied only during daytime), three different times are considered for prediction of the casualty numbers:

1. Nighttime scenario (called 02:00 am): i.e. earthquake striking during night time.
2. Daytime scenario (called 10:00 am): i.e. earthquake striking during day time.
3. Commuting time scenario (called 05:00 pm): i.e. earthquake striking during the commuting time

Table 6: Injury Classification Scale According to Hazus (Multi-Hazard Loss Estimation Methodology, 2003)

Injury Level	Description
Severity 1	Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation.
Severity 2	Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status.
Severity 3	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously.
Severity 4	Instantaneously killed or mortally injured.

Accurate definition of seismic ground motion (level and spectral characteristics of earthquake motion) plays important roles in seismic risk assessment. In order to accomplish a seismic risk and loss assessment using SELENA, seismic ground-motion amplitudes can be defined in three different ways (Multi-hazard Loss Estimation Methodology, 2003)

1. Definition of spectral ordinates (taken out from probabilistic seismic maps) for each geographical region (probabilistic analysis).
2. Specification of deterministic earthquake scenarios (e.g., historical or user-defined events) and appropriate ground-motion prediction equations, in order to compute the spectral ordinates in each geographical region (deterministic analysis).
3. Definition of recorded ground-motion amplitudes at the locations of seismic (strong-motion) stations (analysis with real-time data).

Amplification of Ground Motion for Design Spectra

In case those sedimentary soil materials are present at a site, the seismic ground motion at the ground surface is modified both in amplitude and frequency content. Respective amplification factors and/or corner periods which basically describe shape of the design spectra for the different soil classes are given in the corresponding code provisions. Currently, the procedures of IBC-2006, Eurocode 8 (Type 1 andType2), and Indian standard IS 1893 are incorporated while IBC-2006 is used in this study (Design for structures for earthquake resistance, 2002).

Damage Functions Specification

Building damage functions are in the form of semi logarithmic fragility curves which relate the probability of reaching or exceeding a building damage state for a given PESH (Potential earth science hazards) demand parameter (e.g., displacement response spectrum). Figure 3 provides an example of fragility curve for four damage states used in this methodology (Molina, D.H. Lang, C.D. Lindholm, F. Lingvall, 2010).

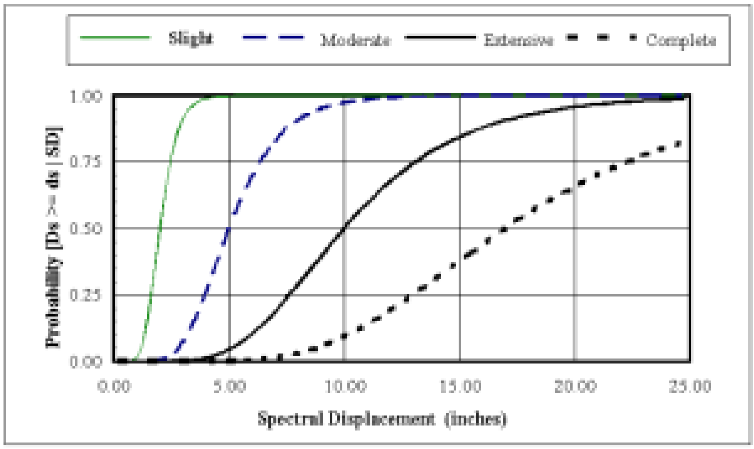

Figure 3: Fragility Curves for Slight, Moderate, Extensive and Complete Damage

Each fragility curve is defined by a mean value of the PESH demand parameter (i.e. either spectral displacement, PGD, spectral acceleration, PGA) corresponding to the damage state threshold and its variability. For example, the spectral displacement, S_d, which defines the threshold of a particular damage state (ds) is assumed to be defined as follow (Multi-hazard Loss Estimation Methodology, 2003)

$$S_d = S_{d,ds} \times \varepsilon_d$$

Where $S_{d,ds}$ is the mean value of spectral displacement for damage state, ds, and ε_d is a lognormal random variable with unit median and logarithmic standard deviation.

Structural Performance under Seismic Action

In order to determine the seismic performance of a building, the spectral displacement along its capacity curve must be determined that is consistent with the seismic demand and at the same time being reduced for nonlinear effects. Currently a number of different methodologies are available in order to identify the so-called performance point on the capacity spectrum. In the following the CSM as proposed byATC-40and (FEMA 273), a recent modification of this procedure, the MADRS method, and the displacement coefficient method (DCM) of (FEMA-356) with the improvements proposed in (FEMA-440) [referred henceforth as improved displacement coefficient method (I-DCM)] will be described to determine the performance point and thus to establish the basis in order to estimate the structural damage state under an estimated seismic demand. MADRS method is used in this study (Federal Emergency Management Agency, 1996a)

Probabilistic Analysis

The probabilistic analysis procedure denotes the use of spectral ordinates which are taken from probabilistic seismic maps. In addition to the acceleration values (PGA, Sa_T) for each geographical region, the geographical coordinates of the centroid have to be provided. Probabilistic seismic maps are generally developed for rock conditions such that soil amplification is not included in the spectral ordinates (Multi-hazard Loss Estimation Methodology, 2003).

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Output files of this software are consist of mean damage ratio (MDR), economic losses, damaged building area, number of human losses and damage probabilities.
Because of high volume data, ArcGis software is implemented in order to show results.

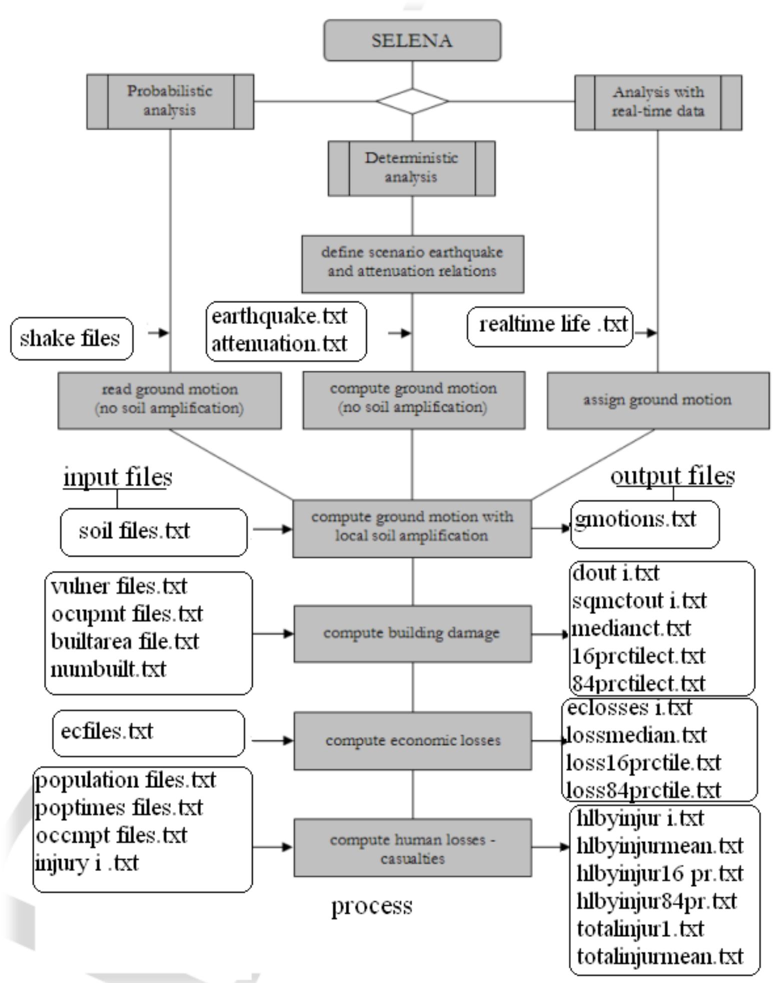

Figure 4: Flowchart of Selena

Figure 5: Amount of Economic Losses of Shiraz

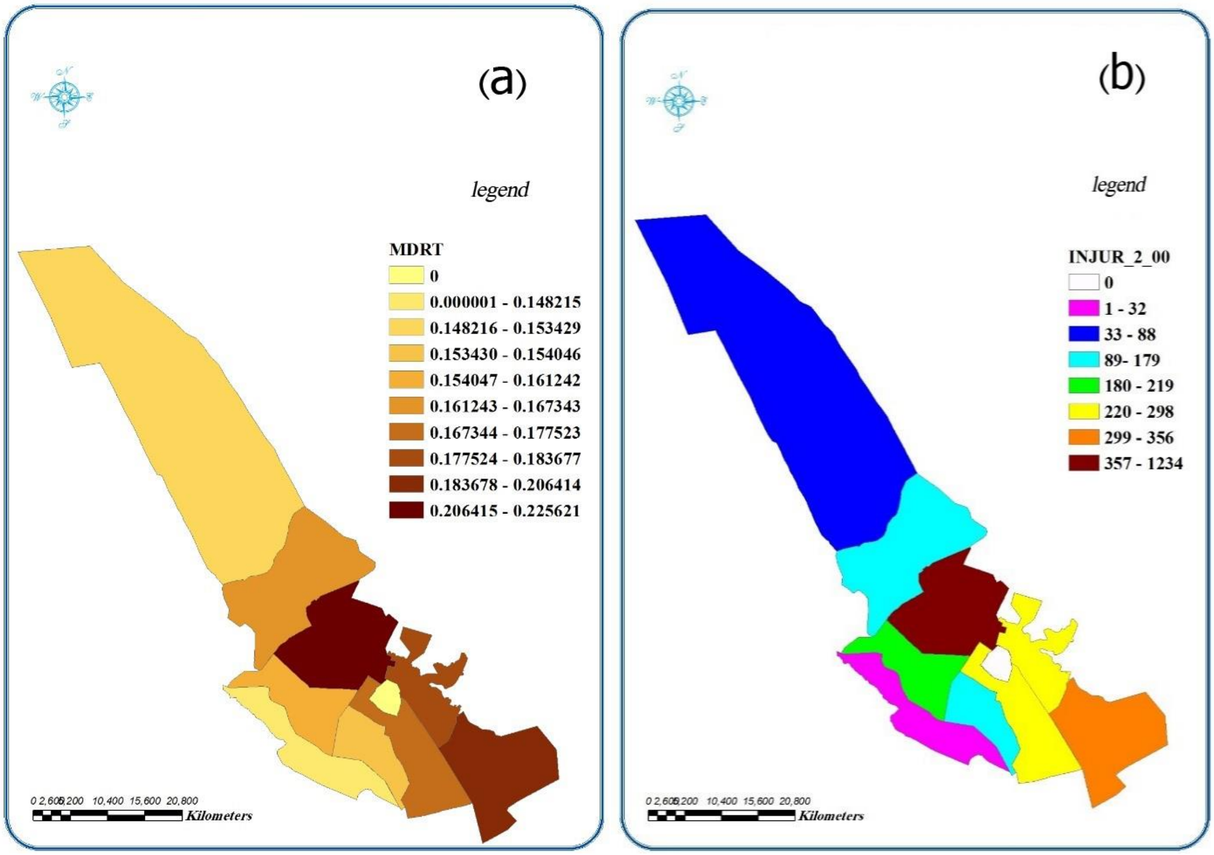

Figure 6: (a) Mean Damage Computed for Different zone of Shiraz, (b) Casualties At 2.00 am

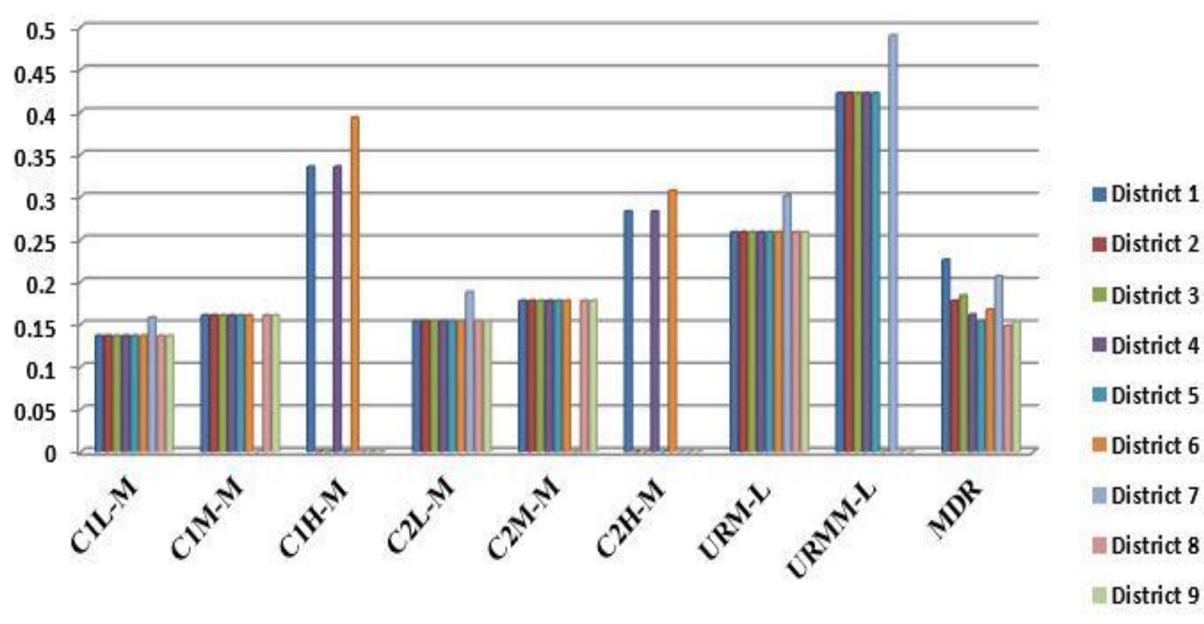

Figure 7: Mean Damage Ratio Computed for Concrete and Masonry Structures

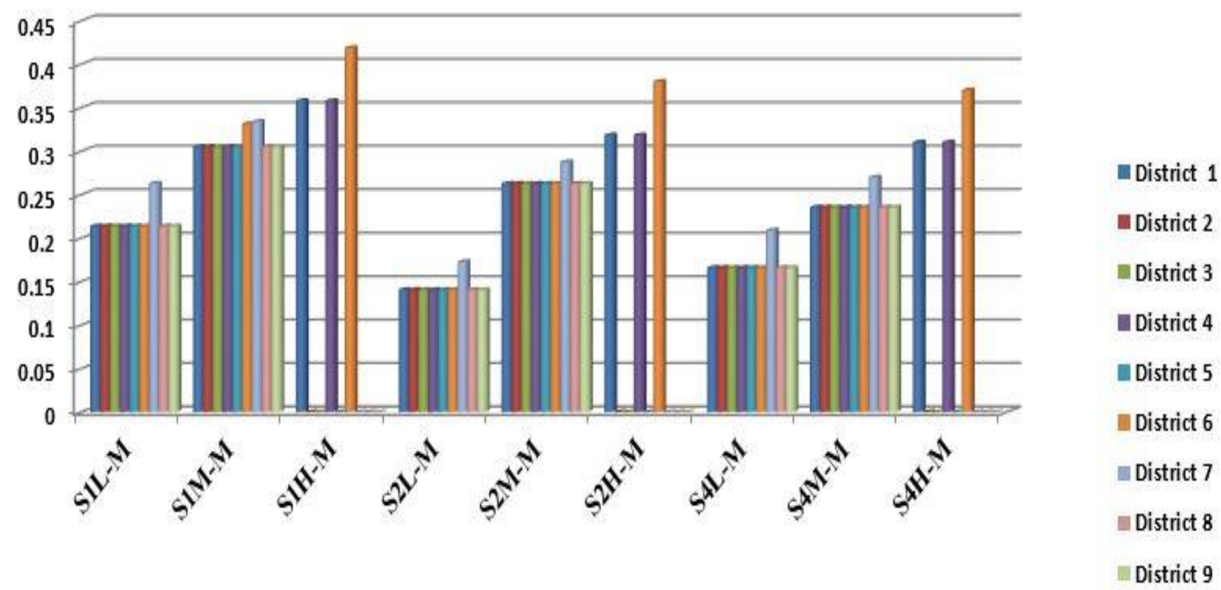

Figure 8: Mean Damage Ratio Computed for Steel Structures

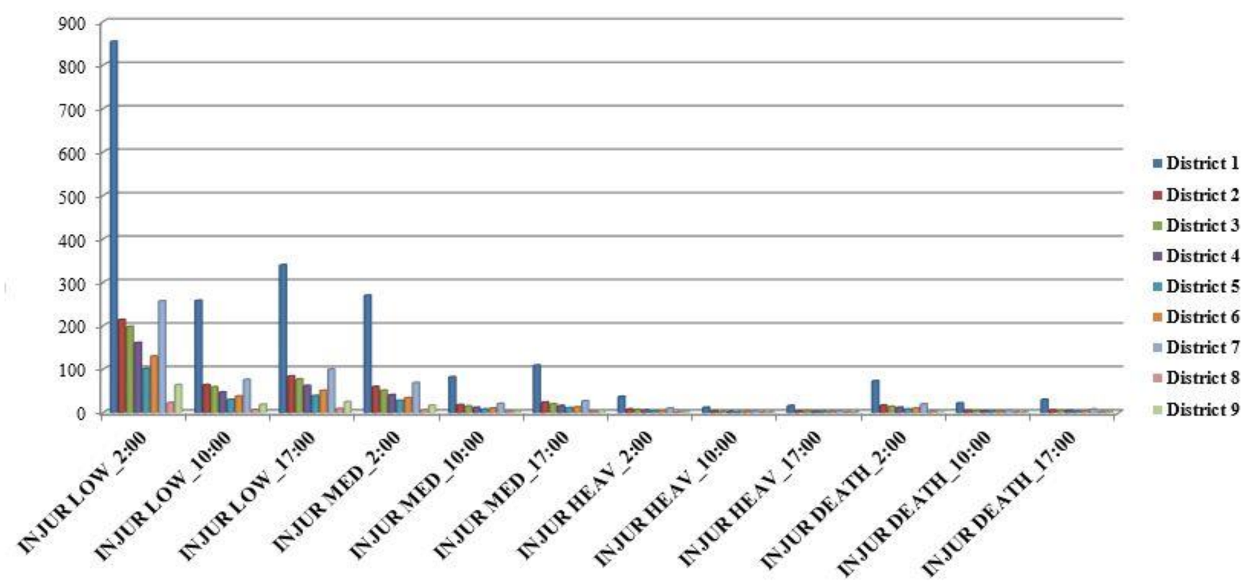

Figure 9: Amount of Casualties of the Earthquake Base on Std. 2800 (Person)

RESULTS AND DISCUSSION

According to our calculations, and outputs the result of the application of the above observations, we realize the greatest casualties arrived at 2 am and the maximum amount of the losses in the region of 1 (57 percent of the total) have, and that of course result. Since, this time, more people are at home at rest is common sense.

Due to the high density of structures in the region, 32% of steel, 46% of concrete and 22% of masonry structures as well as the fact that this region populated and vulnerable areas of the city is, it is necessary to review and retrofitting in the region of Bam prevent similar incidents. According to the results shown in the study determines how much damage to the city caused by an earthquake of over 1.125.000.000 \$. Nearly half of the losses in the region is a need to review and re-building of the city.

Appendix

S1L	Steel Moment Frame, low-rise
S1M	Steel Moment Frame, mid-rise
S1H	Steel Moment Frame, high-rise
S2L	Steel Braced Frame, low-rise
S2M	Steel Braced Frame, mid-rise
S2H	Steel Braced Frame, high-rise
S4L	Steel Frame with Cast-in-Place Concrete Shear Walls, low- rise
S4M	Steel Frame with Cast-in-Place Concrete Shear Walls, mid- rise
S4H	Steel Frame with Cast-in-Place Concrete Shear Walls, high- rise
C1L	Concrete Moment Frame, low rise
C1M	Concrete Moment Frame, mid rise
C1H	Concrete Moment Frame, high rise
C2L	Concrete Shear Walls, low rise
C2M	Concrete Shear Walls, mid rise
C2H	Concrete Shear Walls, high rise
URML	Unreinforced masonry bearing walls, low rise
URMM	Unreinforced masonry bearing walls, mid rise

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