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Earthquake Building Risk Assessment in Sana'a city, Yemen

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Seismological and Volcanological Observatory Center (SVOC)

Ministry of Oil & Minerals

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(2)Main Research Objectives

- Building Damage Prediction at Sana'a city by Developing Historical Earthquake Scenarios and investigate the behavior of buildings during the strong earthquakes.

- Improvement our Disaster Management Planning through rising preparedness at city level.

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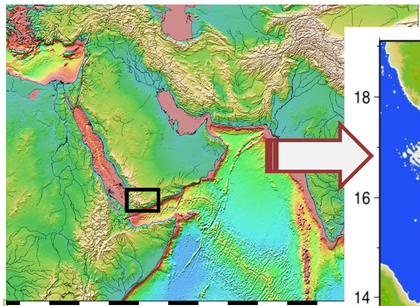
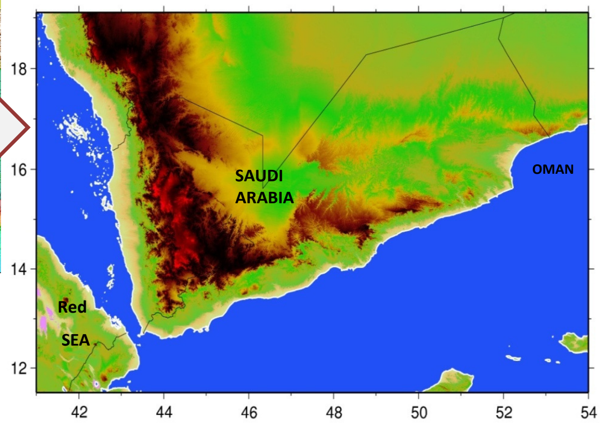
GENERAL INFORMATION





Location:

Yemen is located in the southern west of the Arabian peninsula.

AREA :
528,000 km², 21 Governorate

POPULATION:
22 million.

- **Topography**

  The country's topography of Rugged Mountains, Volcanic Highlands, Deserts, and Coastal plains.

- **Geo-Tectonic setting**

  (Arabian plate) is bordered by active seismic zone : the Red Sea from the west and Gulf of Aden from the south..

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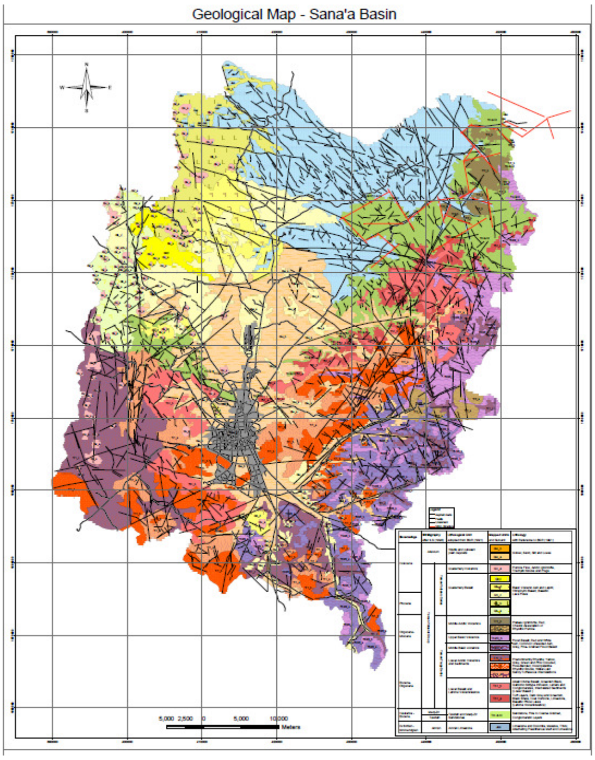
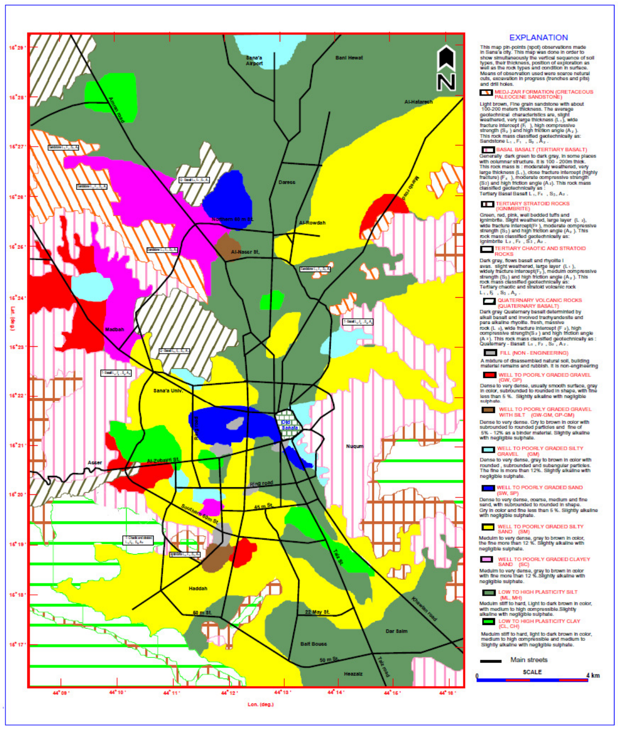
Geology and Tectonic





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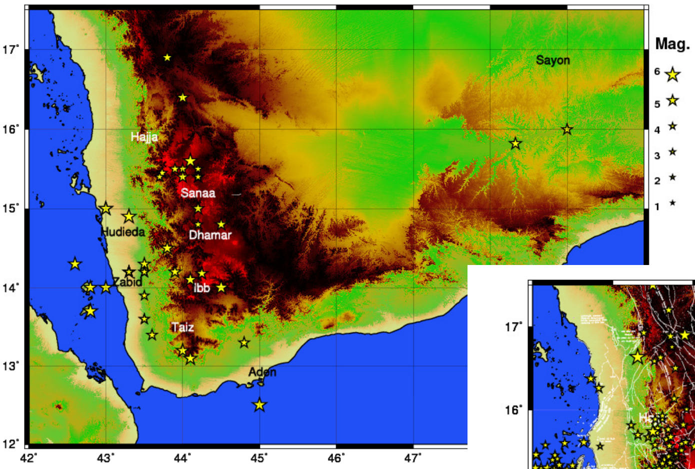
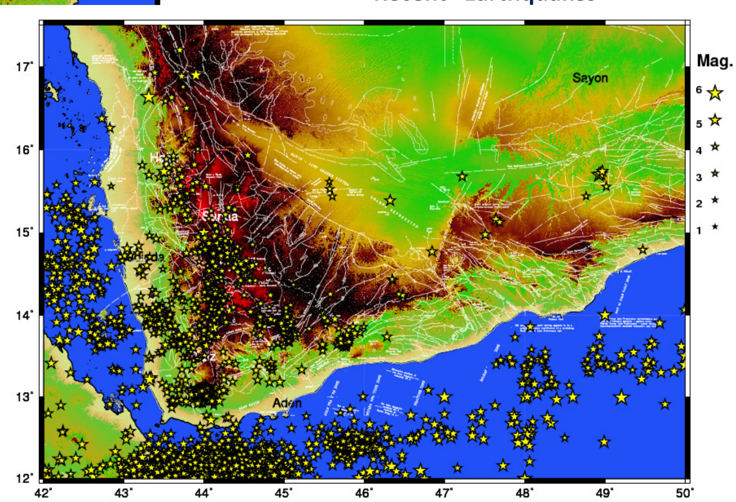
Earthquakes in Yemen and Sana'a region



Historical Earthquakes

Recent Earthquakes



Identified Yemenis Building Types

Example : Un-Reinforcement Masonry Building types (URM)

Burnt Brick

Burnt Brick + stone

clay

block

Example : Reinforcement Masonry Building types (RM) filled by block stone and bricks

Concrete Filled by block

Concrete Filled by stones &brick

Example : Reinforcement Masonry Building types (RM) filled by stone

Concrete Filled by Heavy stones

Concrete Filled by Heavy stones

Concrete Filled by light stones

Building inventory and Data Base Preparation.

جدول يبين عدد المساكن والأسر والسكان المقيمين على مستوى التقسيمات الإدارية (التجمعات السكانية)

عدد الأسر	عدد المساكن	الحارة/المحلة	رمز الحارة/المحلة	المدينة/القرية	رمز المدينة/القرية	الحي	رمز الحي	العزلة	رمز العزلة	المديرية	رمز المديرية	المحافظة	رمز المحافظة
375	378	غمدان	1	الامانة	1	صنعاء القديمة	1	صنعاء القديمة	21	صنعاء القديمة	1	الامانه	13
104	110	الخارجية	2	الامانة	1	صنعاء القديمة	1	صنعاء القديمة	21	صنعاء القديمة	1	الامانه	13
252	254	خضير صرحة الوادي	3	الامانة	1	صنعاء القديمة	1						
40	40	خضير	4	الامانة	1	صنعاء القديمة	1						
343	319	الطواشي	5	الامانة	1	صنعاء القديمة	1						
320	311	المدرسة	6	الامانة	1	صنعاء القديمة	1						
34	35	البكيرية - مقبرة	7	الامانة	1	صنعاء القديمة	1						
95	92	صلاح الدين	8	الامانة	1	صنعاء القديمة	1						
40	39	المفتون	9	الامانة	1	صنعاء القديمة	1						
169	154	ياسر	10	الامانة	1	صنعاء القديمة	1						
58	54	عقيل	11	الامانة	1	صنعاء القديمة	1						
17	17	سوق المخلاص	12	الامانة	1	صنعاء القديمة	1						
51	53	المصباغة	13	الامانة	1	صنعاء القديمة	1						
6	4	النظارة - الجديد	14	الامانة	1	صنعاء القديمة	1						
26	25	المذهب	15	الامانة	1	صنعاء القديمة	1						
259	256	غرفة القليس	16	الامانة	1	صنعاء القديمة	1						
53	50	الميدان	17	الامانة	1								
57	54	الابزر	18	الامانة	1								
164	164	الباشا	19	الامانة	1								
67	63	باب السلام	20	الامانة	1								
44	46	سكرة	21	الامانة	1	صنعاء القديمة	1						
111	98	نصير	22	الامانة	1	صنعاء القديمة	1						
76	75	موسى	23	الامانة	1	صنعاء القديمة	1						
68	63	الحميدي	24	الامانة	1	صنعاء القديمة	1						
89	84	باب اليمن	25	الامانة	1	صنعاء القديمة	1						
189	197	بحر رجرج	26	الامانة	1	صنعاء القديمة	1						
108	110	الحسوسة	27	الامانة	1	صنعاء القديمة	1						
412	411	الجامع الكبير	28	الامانة	1	صنعاء القديمة	1						

RC+Block 1

	Population Nu	Building Num.		Building ty	(I)						Num.of Floor	(J)	Age	(K)
Destrict Name			RC	Stone	Block	RC+Stone	RC+Block	rick+ston	clay	1_3	4_6	>6	Before 1982	After 1982
Old sana`a	63398	9725					0			0	0	0		
Shuaub	213939	33036					4800			4494	226	86		*
Azal	115054	16396					2382			2231	112	43		*
Al-Safiya	109109	16207					2355			2205	111	42		*
Al-Sabain	311203	46876					6811			6377	321	123		*
Al-Wahdah	99596	16405					2384			2232	112	43		*
Al-Tahrir	66898	11169					1623			1519	76	29		*
Ma`ain	265469	42983					6245			5848	294	112		*
Al-Thawra	170145	26426					3840			3595	181	69		*
Bani_Al-harith	184509	25743					3276			3067	154	59		*
Dhawahi Hamdan	26259	4338					326			305	15	6		*
Sanhan - Bani_ Bahlol	122255	17822					2322			2174	109	42		*
TOTAL	1747834	267126												

RC STONE 2

	Population Nu	Building Num.		Building ty	(I)						Num.of Floor	(J)	Age	(K)
Destrict Name			RC	Stone	Block	RC+Stone	RC+Block	rick+ston	clay	1_3	4_6	>6	Before 1982	After 1982
Old sana`a	63398	9725				0				0	0	0	*	
Shuaub	213939	33036				12593				11791	593	227		*
Azal	115054	16396				6250				5852	294	113		*
Al-Safiya	109109	16207				6178				5785	291	111		*
Al-Sabain	311203	46876				17869				16731	842	322		*
Al-Wahdah	99596	16405				6254				5855	295	113		*
Al-Tahrir	66898	11169				4258				3986	201	77		*
Ma`ain	265469	42983				16385				15341	772	295		*
Al-Thawra	170145	26426				10074				9432	474	181		*
Bani_Al-harith	184509	25743				9813				9188	462	177		*
Dhawahi Hamdan	26259	4338				1654				1548	78	30		*
Sanhan - Bani_ Bahlol	122255	17822				6794				6361	320	122		*
TOTAL	1747834	267126												

BLOCK 3

	Population Nu	Building Num.		Building ty	(I)						Num.of Floor	(J)	Age	(K)
Destrict Name			RC	Stone	RC+Block	RC+Stone	Block	rick+ston	clay	1_3	4_6	>6	Before 1982	After 1982
Old sana`a	63398	9725					0			0	0	0	*	

Sheet1 Sheet2 Sheet3

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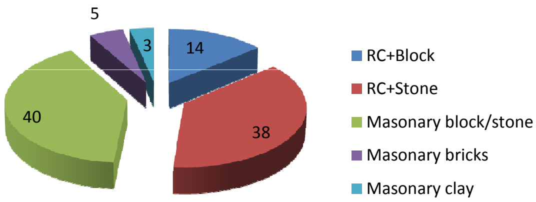
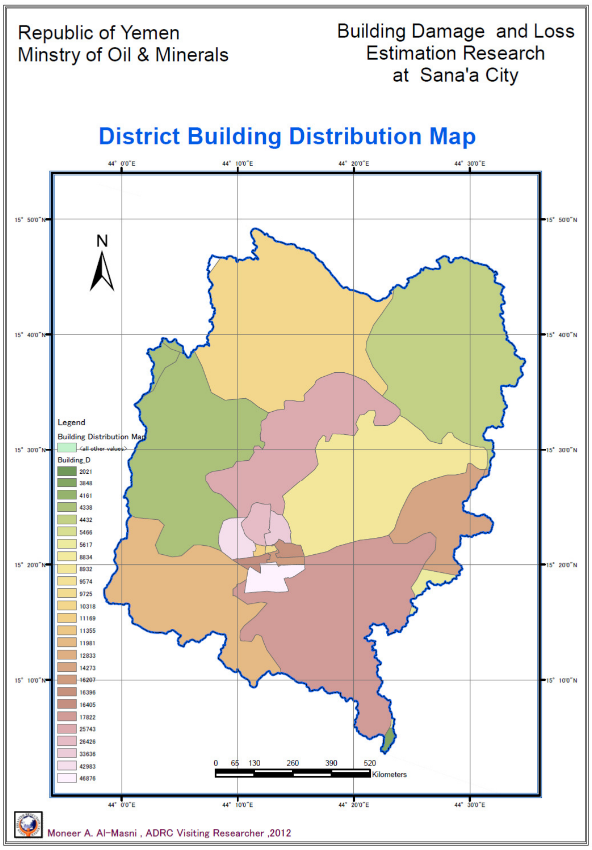
Building Distribution in Sana'a City





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Example for Classification of Building Types According to Existing Database

Construction Type (I)

1.Reinforced concrete building filled with Blok
2.Reinforced concrete building filled with Stone
3. Masonry (Stone/concrete Block) buildings
4. Masonry (Bricks) buildings
5. Masonry (Clay) buildings

Number of stories (J)

1. Low -rise (1-3 stories)
2. Mid -rise (4-6 stories)
3. High-rise (more than 6 stories)

Construction date (K)

1. Construction year: Pre-1982
2. Construction year: Post-1982

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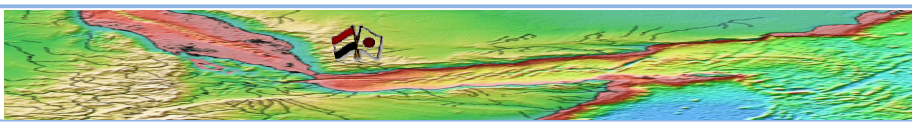
Seismic level Design in Buildings — HAZUS

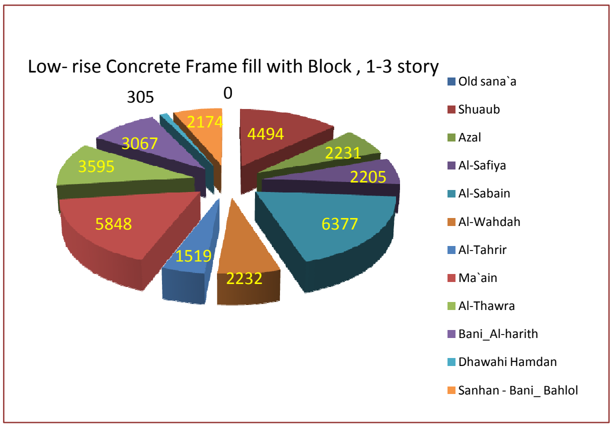
No.	Description	Height	Stories	HAZUS type	Code level
Masonry consisting of Rectangular Units					
9	Burnt clay brick/ rectangular stone in mud mortar	R1, R2	1-2		Not Defined
10		R3, R4	1-2		
11		R5	1-2		
12	Burnt clay brick/ rectangular stone in lime-surkhi mortar	R1, R2	1-2		
13		R3, R4	1-2		
14		R5,R6	1-2		
15	Burnt clay brick/ rectangular stone/ concrete blocks in cement mortar	R1, R2	1-2		
16		R3, R4	1-2		
17		R5,R6	1-2		
18			3+		
19	Burnt clay brick/ rectangular stone/ concrete blocks in cement mortar and provided with seismic bands and vertical reinforcement at corners and jambs	R5,R6	1-2		Not Defined
20			3+		
Framed Structures					
21	RC frame/ shear wall with URM infill's – constructed without any consideration for earthquake forces	R-6	1-3	C3L	Precode
22			4-7	C3M	
23	RC frame/ shear wall with URM infill's - earthquake forces considered in design but detailing of reinforcement and execution not as per earthquake resistant guidelines (Low-Code/Moderate Code)		1-3	C3L	Precode/Low code
24			4-7	C3M	
25			8+	C3H	
26	RC frame/ shear wall with URM infill's - designed, detailed and executed as per earthquake resistant guidelines (Low-Code/ Moderate-Code/High Code)		1-3	C3L	Precode/Low code/Moderate Code
27			4-7	C3M	
28			8+	C3H	

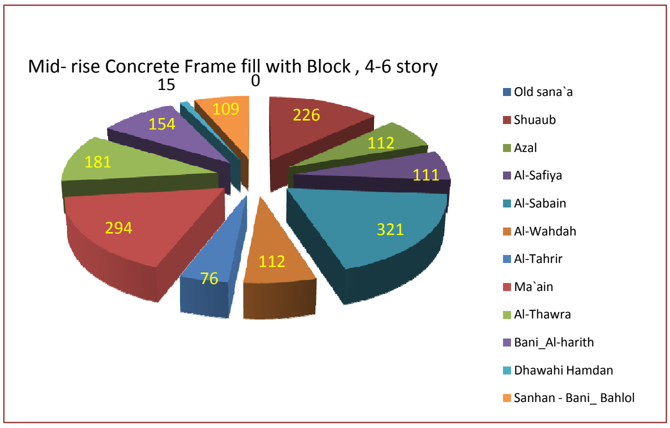
pre-code

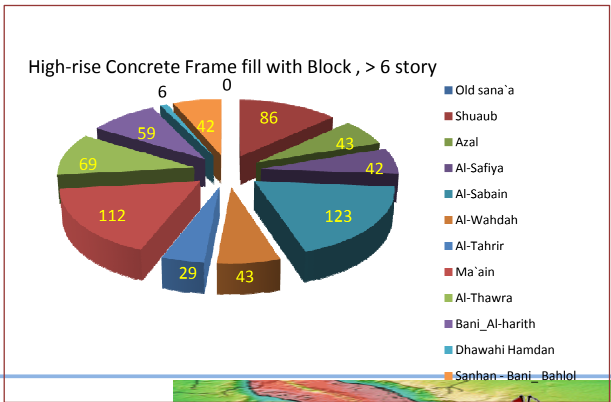
Low-code

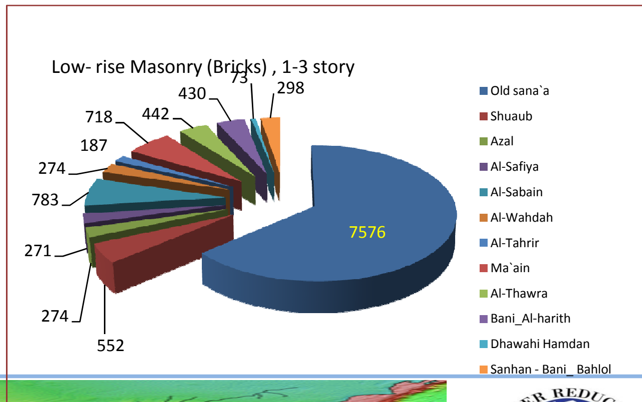


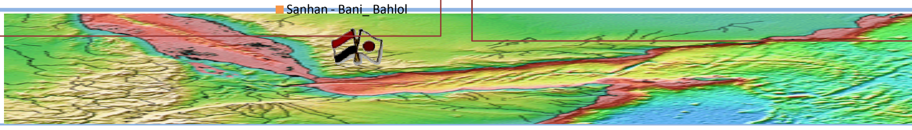
Example Results of Buildings classification











Application Of HAZUS Methodology in Sana'a

Earthquake Risk Assessment

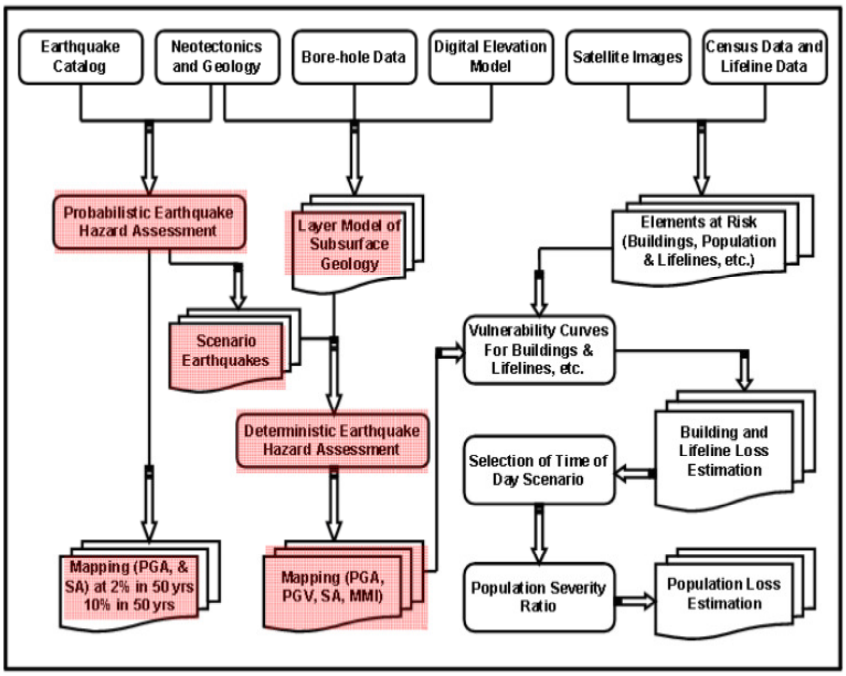
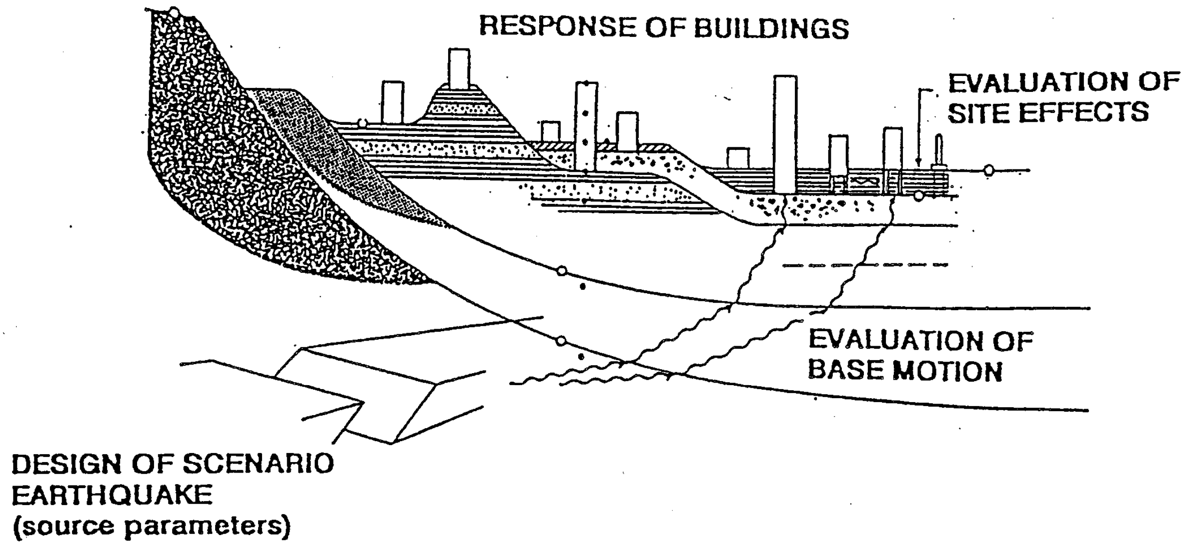
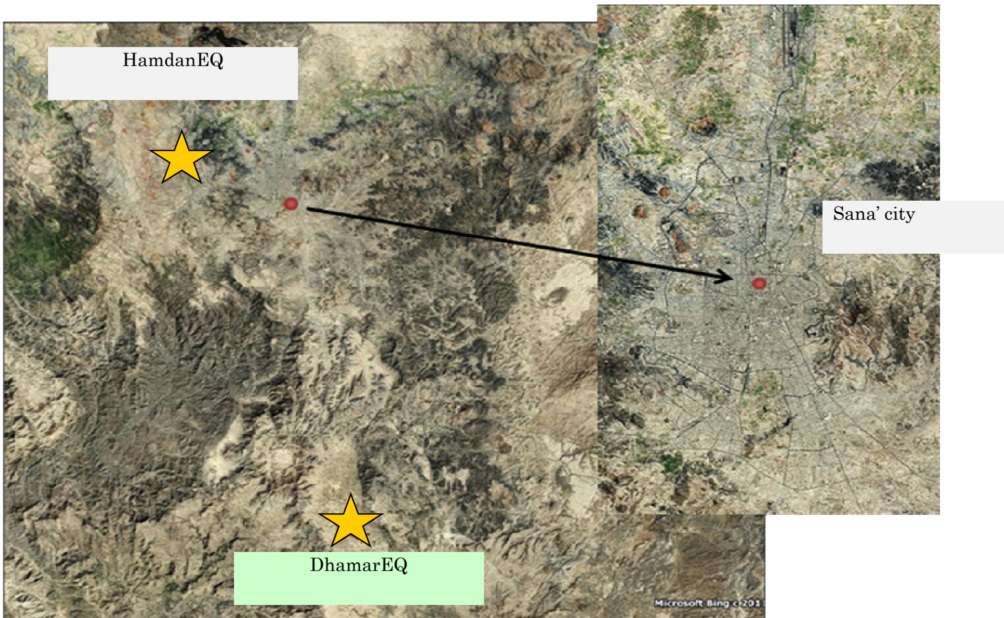


diagram show the methodology used for risk assessment analysis

Simulation of Earthquake Scenarios.



Development of Earthquake Scenarios.



Fault_DHMAR Browser

FAULTX	FAULTY
6.2	6.1
44.37	14.91
44.37	14.89
44.38	14.8
44.38	14.7

Fault_WESTSana Browser

FAULTX	FAULTY
6	5.9
43.95	15.53
43.96	15.51
44.01	15.45
44.02	15.44
44.02	15.43

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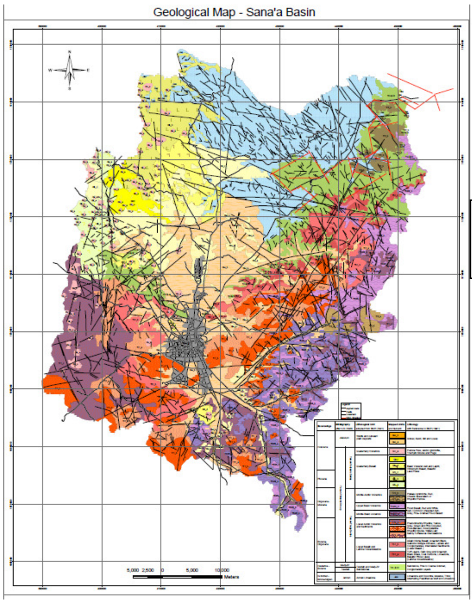
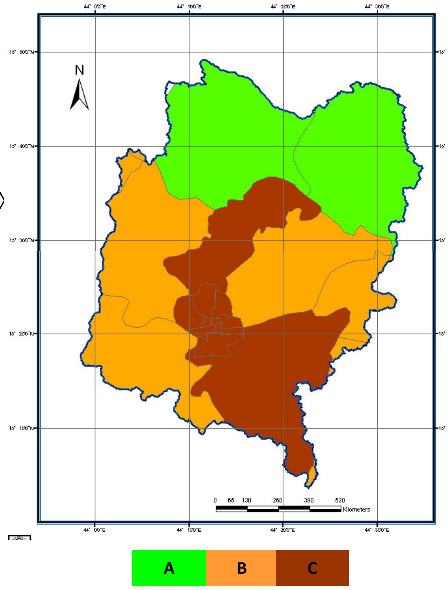
Site effects , Soil Conditions and Classification

Based on AVS30m and NEHRP guidelines geological unites divided to 3 Groups





Attenuation Model and soil condition

$$Ln\left(\left(S_A\right)\right) = b1 + b2(M-6) + b3(M-6)2 + b5\,Ln(r) + bvLn\left(\frac{Vs}{VA}\right)$$

Where

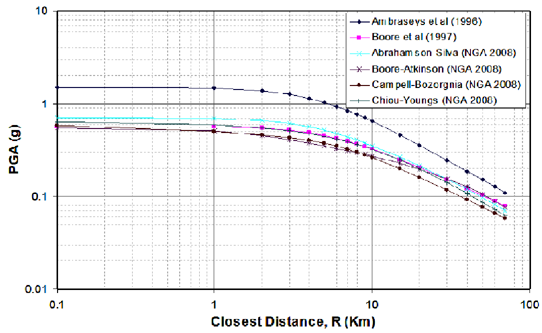
$$r = \sqrt{r_{jb}^2 + h^2}$$

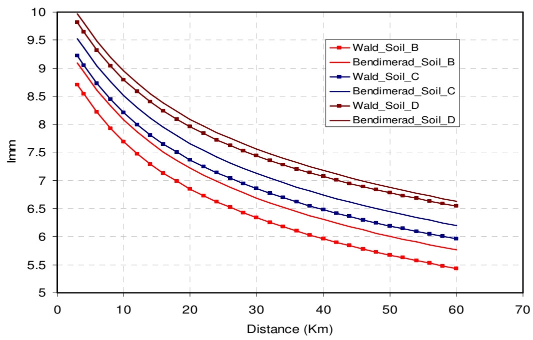
And

$$b1 = \begin{cases} b1_{ss} & \text{For strike-Slip earthquakes} \\ b1_{Rv} & \text{For reverse Slip earthquakes} \\ b1_{all} & \text{If mechanism not specified} \end{cases}$$

S_A	is spectral acceleration to be derived
b_1,b_2,b_3,b_5,b_v	are constants provided with the equation
M	is the magnitude of the earthquake
r_{jb}	is the horizontal distance from epicenter
V_s	the shear wave velocity of the soil class provided by NEHRP classification

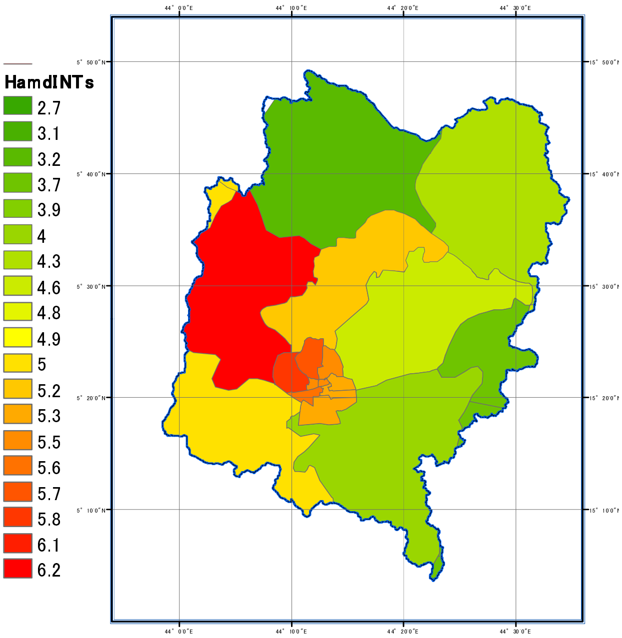
*Imm= 1.6 * Ln PGA+ 0.545 * Mw +5.78*



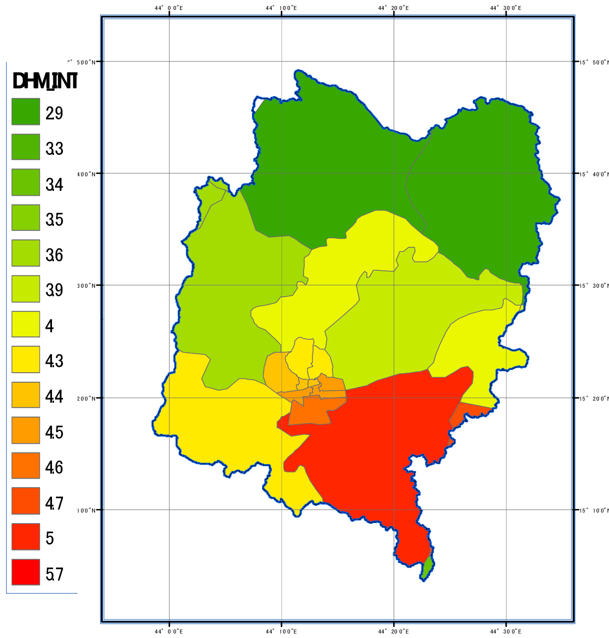


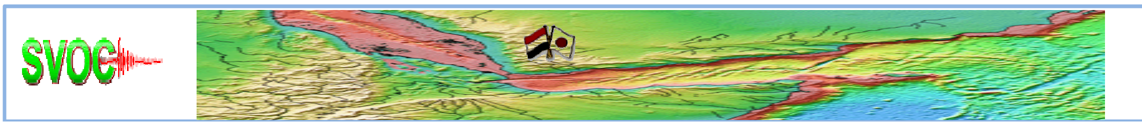
Seismic Intensity MAP

HAMDAN_EQ. SCENARIO



DHAMAR_EQ. SCENARIO





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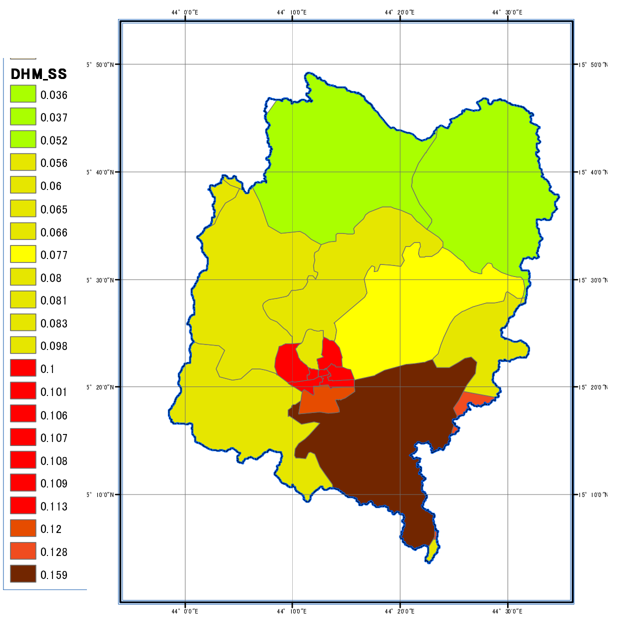
Spectral Acceleration MAP

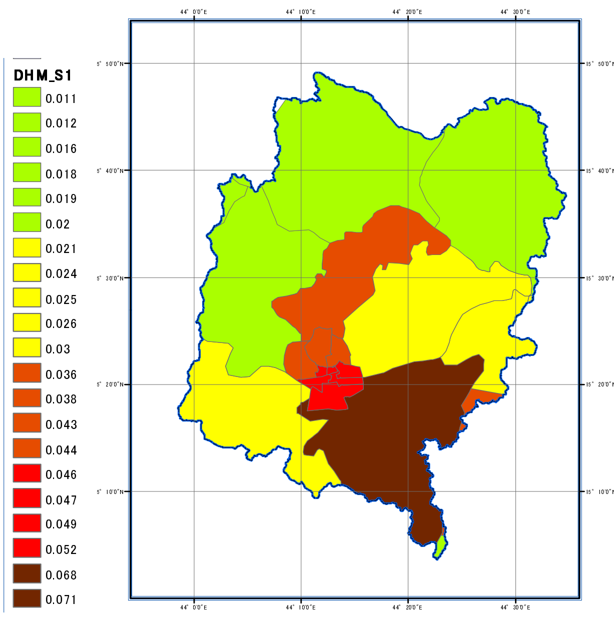
Short period Spectral Acceleration MAP、0. 2s

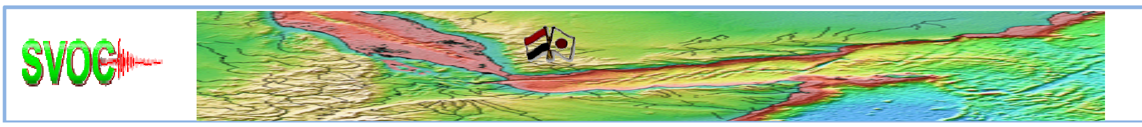
DHMAR_EQ. SCENARIO



Long period Spectral Acceleration MAP、1. 0s

DHAMAR_EQ. SCENARIO





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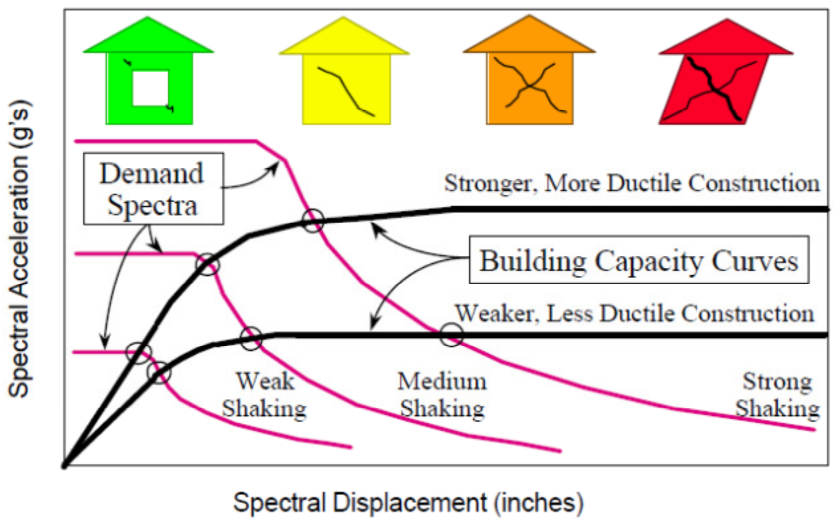
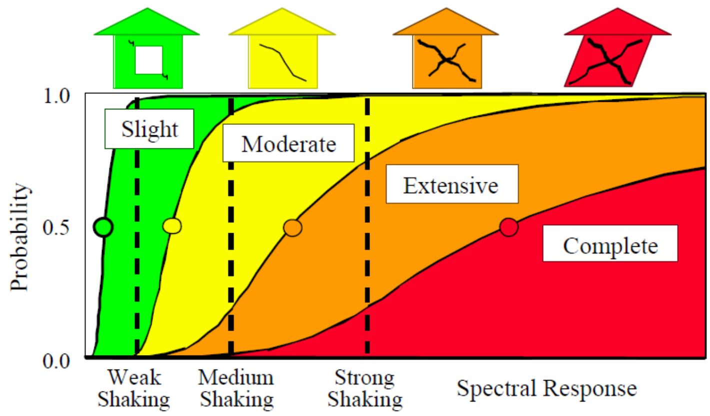
Building Damage Analysis

1)Building Response Calculation



2）Building Fragility Curves

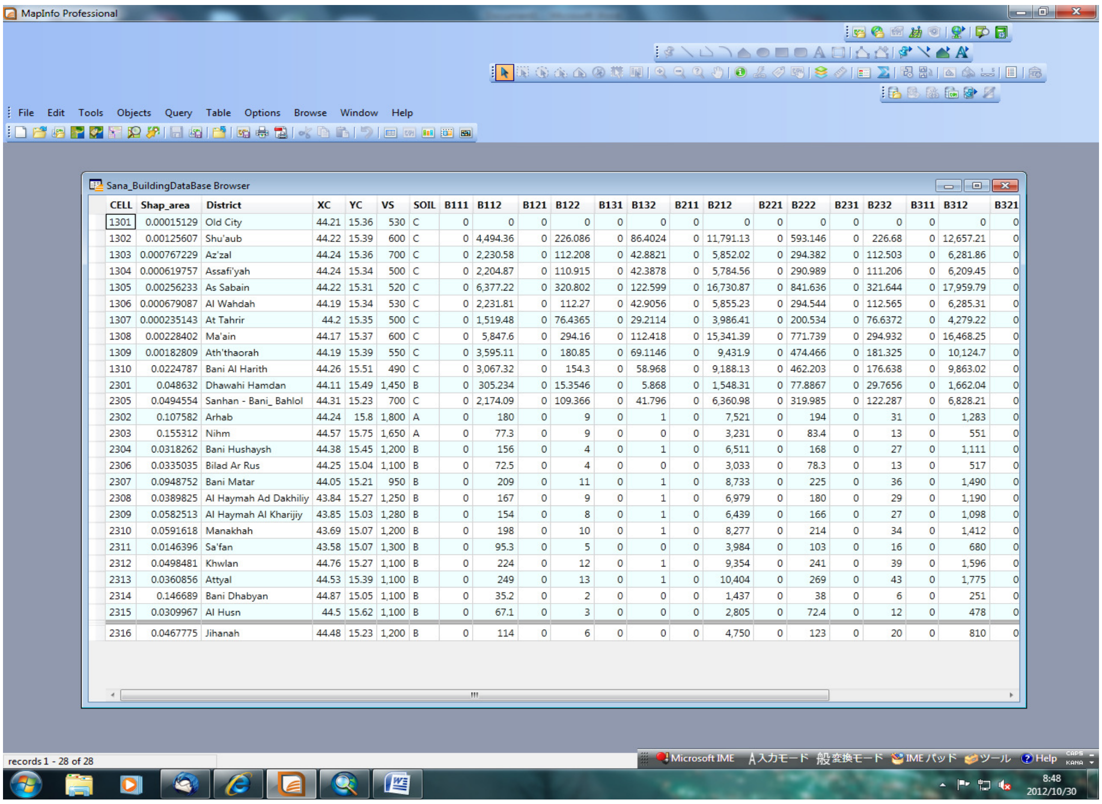


$$P\left[ds \middle| S_d\right] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right]$$

where:

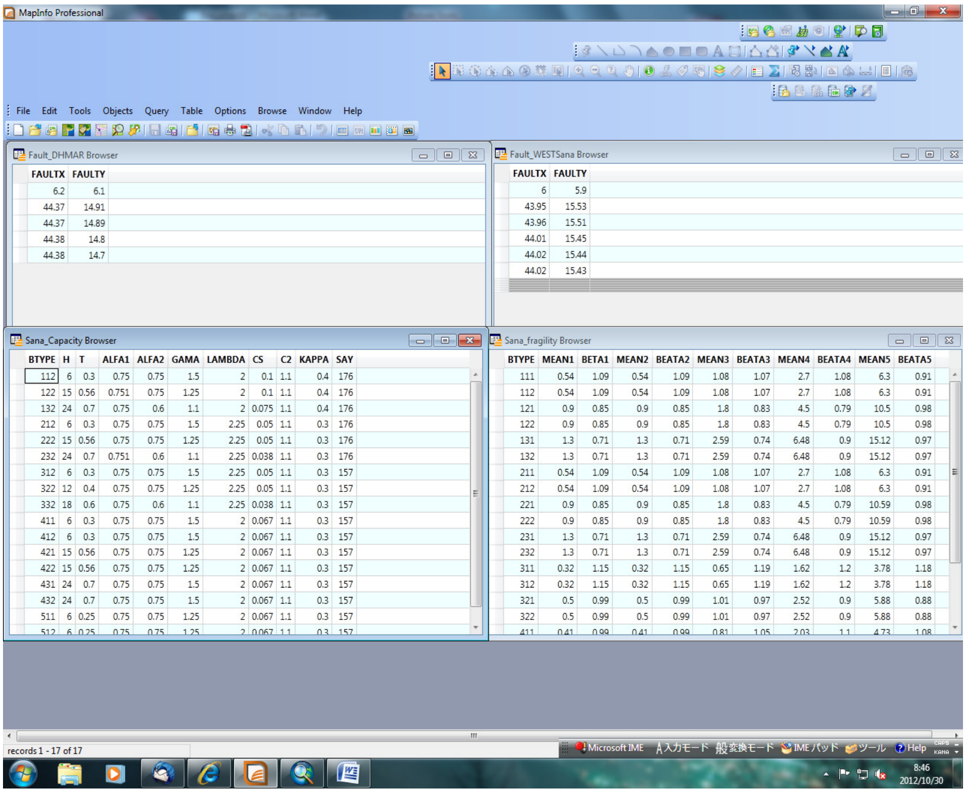
- $\bar{S}_{d,ds}$ is the median value of spectral displacement at which the building reaches the threshold of damage state, ds,
- β_{ds} is the standard deviation of the natural logarithm of spectral displacement for damage state, ds, and
- Φ is the standard normal cumulative distribution function.

Set up Input building data base and site condition as HAZUS Method

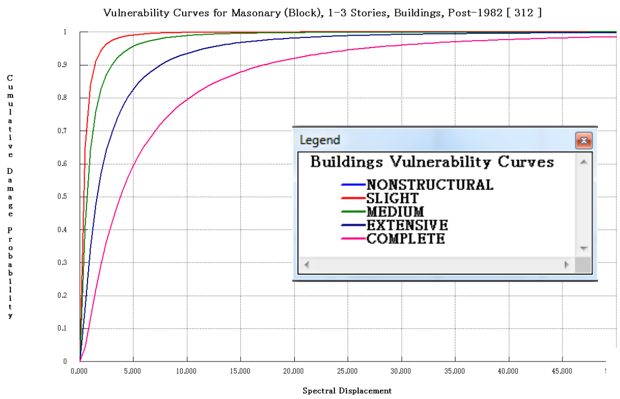


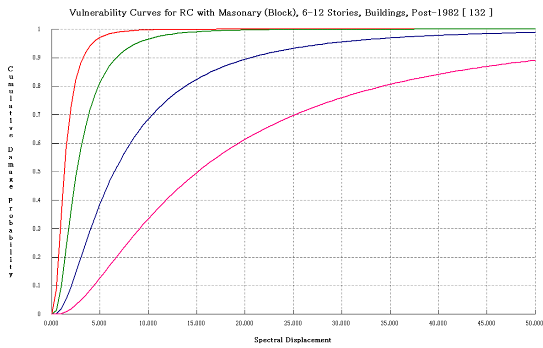
CELL	Shap_area	District	XC	YC	VS	SOIL	B111	B112	B121	B122	B131	B132	B211	B212	B221	B222	B231	B232	B311	B312	B321
1301	0.00015129	Old City	44.21	15.36	530	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1302	0.00125607	Shu'aub	44.22	15.39	600	C	0	4,494.36	0	226.086	0	86.4024	0	11,791.13	0	593.146	0	226.68	0	12,657.21	0
1303	0.000767229	Az'zal	44.24	15.36	700	C	0	2,230.58	0	112.208	0	42.8821	0	5,852.02	0	294.382	0	112.503	0	6,281.86	0
1304	0.000619757	Assafi'yah	44.24	15.34	500	C	0	2,204.87	0	110.915	0	42.3878	0	5,784.56	0	290.989	0	111.206	0	6,209.45	0
1305	0.00256233	As Sabain	44.22	15.31	520	C	0	6,377.22	0	320.802	0	122.599	0	16,730.87	0	841.636	0	321.644	0	17,959.79	0
1306	0.000679087	Al Wahdah	44.19	15.34	530	C	0	2,231.81	0	112.27	0	42.9056	0	5,855.23	0	294.544	0	112.565	0	6,285.31	0
1307	0.000235143	At Tahrir	44.2	15.35	500	C	0	1,519.48	0	76.4365	0	29.2114	0	3,986.41	0	200.534	0	76.6372	0	4,279.22	0
1308	0.00228402	Ma'ain	44.17	15.37	600	C	0	5,847.6	0	294.16	0	112.418	0	15,341.39	0	771.739	0	294.932	0	16,468.25	0
1309	0.00182809	Ath'thaorah	44.19	15.39	550	C	0	3,595.11	0	180.85	0	69.1146	0	9,431.9	0	474.466	0	181.325	0	10,124.7	0
1310	0.0224787	Bani Al Harith	44.26	15.51	490	C	0	3,067.32	0	154.3	0	58.968	0	9,188.13	0	462.203	0	176.638	0	9,863.02	0
2301	0.048632	Dhawahi Hamdan	44.11	15.49	1,450	B	0	305.234	0	15.3546	0	5.868	0	1,548.31	0	77.8867	0	29.7656	0	1,662.04	0
2305	0.0494554	Sanhan - Bani_ Bahlol	44.31	15.23	700	C	0	2,174.09	0	109.366	0	41.796	0	6,360.98	0	319.985	0	122.287	0	6,828.21	0
2302	0.107582	Arhab	44.24	15.8	1,800	A	0	180	0	9	0	1	0	7,521	0	194	0	31	0	1,283	0
2303	0.155312	Nihm	44.57	15.75	1,650	A	0	77.3	0	9	0	0	0	3,231	0	83.4	0	13	0	551	0
2304	0.0318262	Bani Hushaysh	44.38	15.45	1,200	B	0	156	0	4	0	1	0	6,511	0	168	0	27	0	1,111	0
2306	0.0335035	Bilad Ar Rus	44.25	15.04	1,100	B	0	72.5	0	4	0	0	0	3,033	0	78.3	0	13	0	517	0
2307	0.0948752	Bani Matar	44.05	15.21	950	B	0	209	0	11	0	1	0	8,733	0	225	0	36	0	1,490	0
2308	0.0389825	Al Haymah Ad Dakhiliy	43.84	15.27	1,250	B	0	167	0	9	0	1	0	6,979	0	180	0	29	0	1,190	0
2309	0.0582513	Al Haymah Al Kharijiy	43.85	15.03	1,280	B	0	154	0	8	0	1	0	6,439	0	166	0	27	0	1,098	0
2310	0.0591618	Manakhah	43.69	15.07	1,200	B	0	198	0	10	0	1	0	8,277	0	214	0	34	0	1,412	0
2311	0.0146396	Sa'fan	43.58	15.07	1,300	B	0	95.3	0	5	0	0	0	3,984	0	103	0	16	0	680	0
2312	0.0498481	Khwlan	44.76	15.27	1,100	B	0	224	0	12	0	1	0	9,354	0	241	0	39	0	1,596	0
2313	0.0360856	Attyal	44.53	15.39	1,100	B	0	249	0	13	0	1	0	10,404	0	269	0	43	0	1,775	0
2314	0.146689	Bani Dhabyan	44.87	15.05	1,100	B	0	35.2	0	2	0	0	0	1,437	0	38	0	6	0	251	0
2315	0.0309967	Al Husn	44.5	15.62	1,100	B	0	67.1	0	3	0	0	0	2,805	0	72.4	0	12	0	478	0
2316	0.0467775	Jihanah	44.48	15.23	1,200	B	0	114	0	6	0	0	0	4,750	0	123	0	20	0	810	0

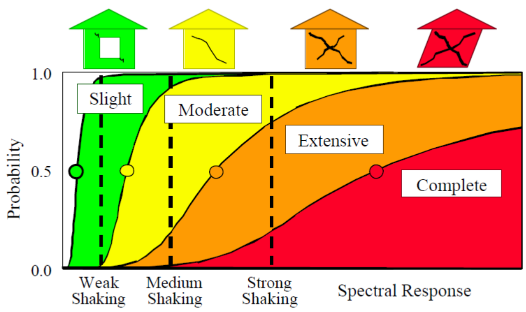
Calculation Fault , fragility and capacity parameters

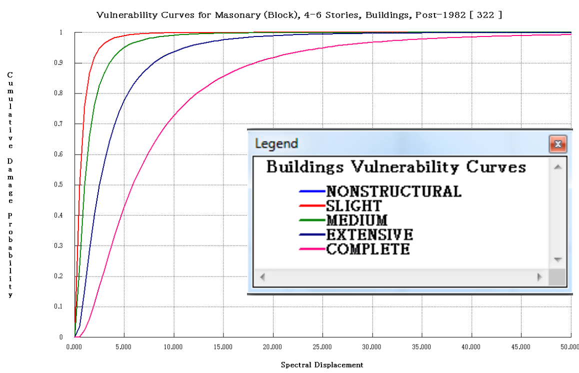


Calculation Vulnerability curves for all URM(Block) buildings

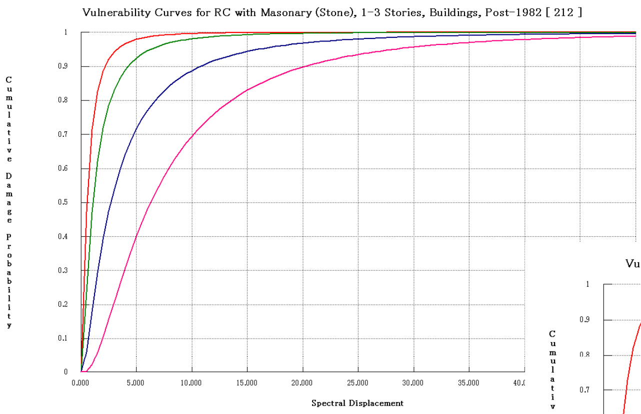


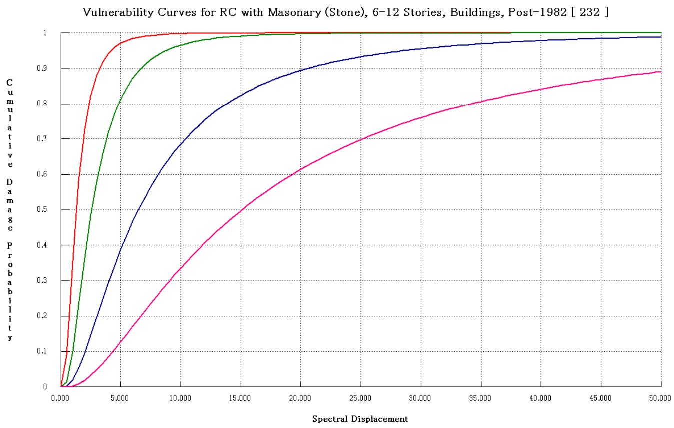




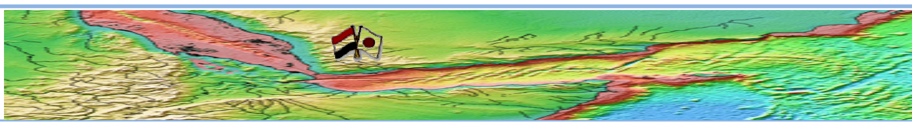


Calculation Vulnerability curves for all RM(Rc+stone) buildings





SVOC



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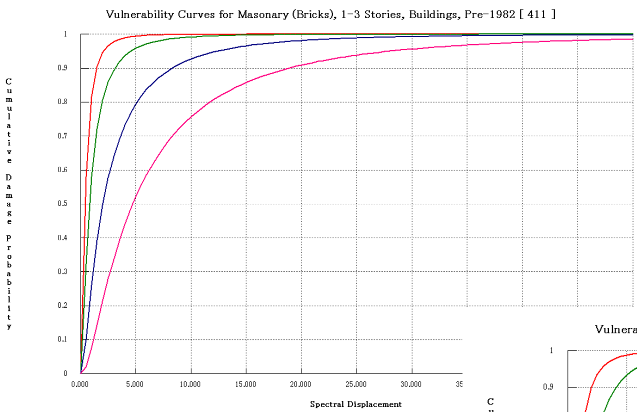
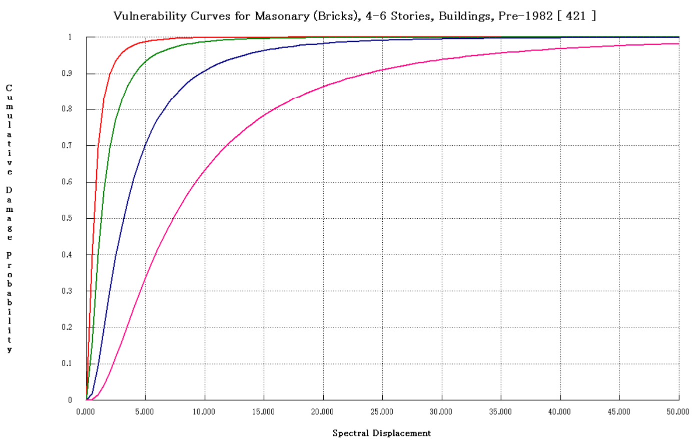
Calculation Vulnerability curves for all URM(bricks) buildings





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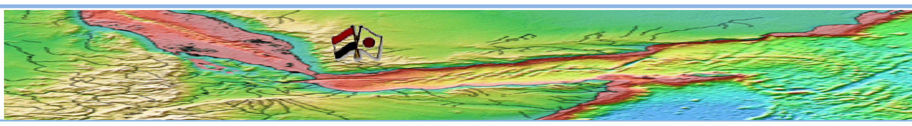

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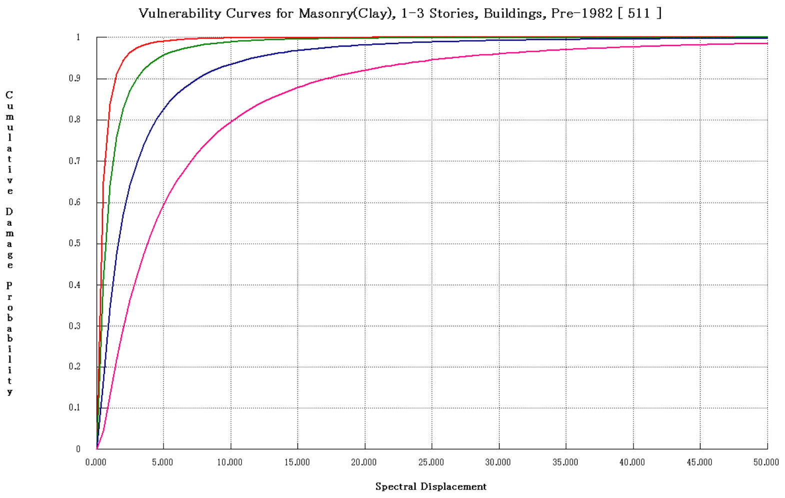
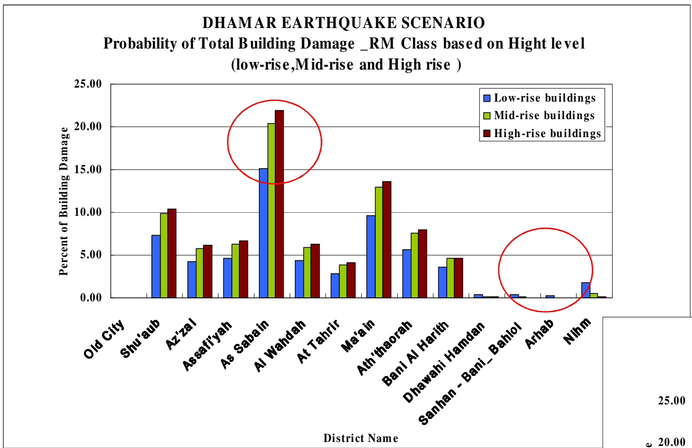
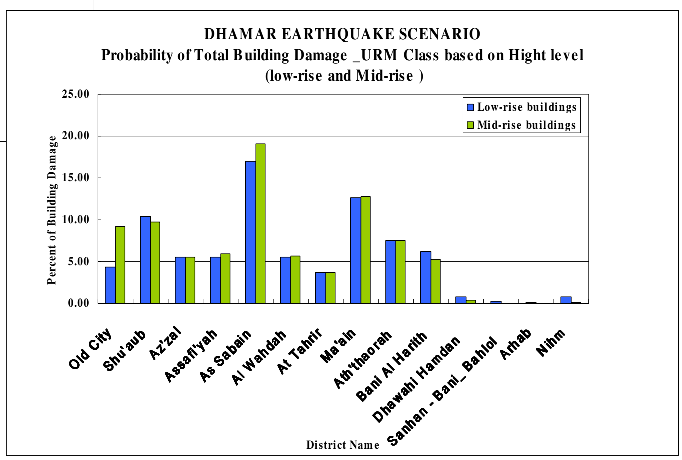
Calculation Vulnerability curves for all URM(clay) buildings

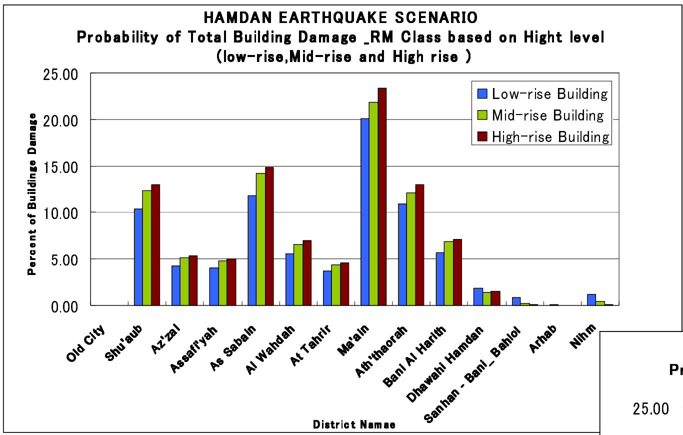


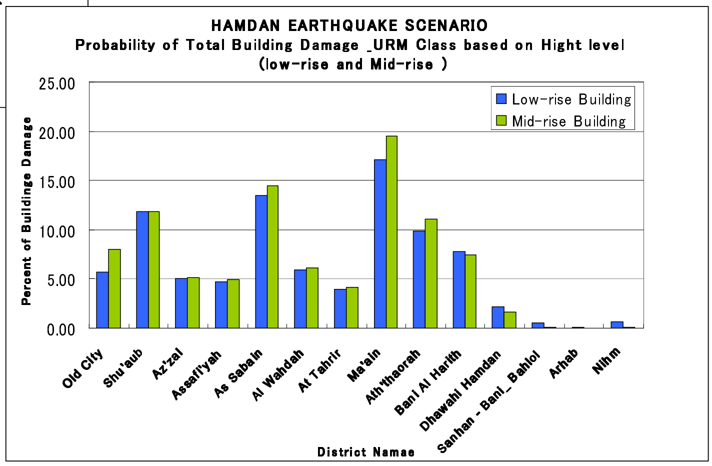
Expected Damage on buildings caused by Dhamar EQ .Scenario





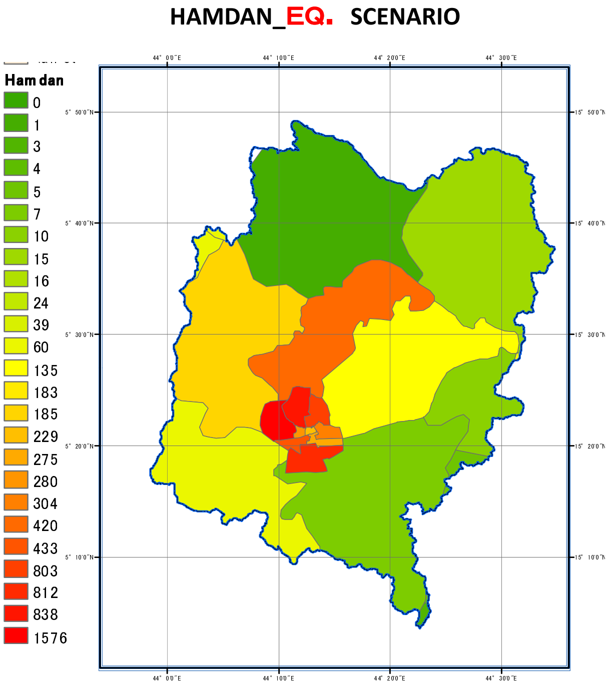
Expected Damage on buildings caused by Hamdan EQ .Scenario

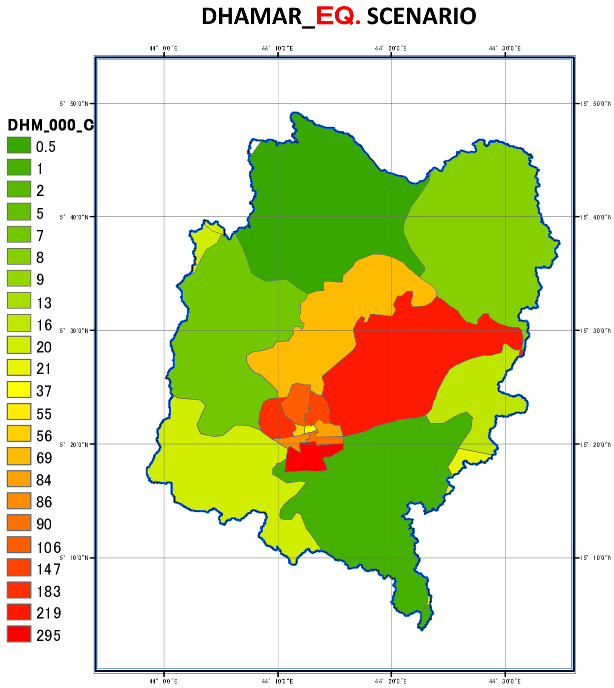




Risk Map in term of completely damage

（Damage Distribution map ）





Discussion and Conclusions

• The initial results of, expected damage on buildings shows overestimation results acceptable at the broad level evaluation. However, the results seem not to be very accurate for fine level risk evaluation.

The graphs indicates that:

• High an Moderate rise buildings (URM or RM) is the most vulnerable to earthquake damage. Whereas low rise buildings is least vulnerable.

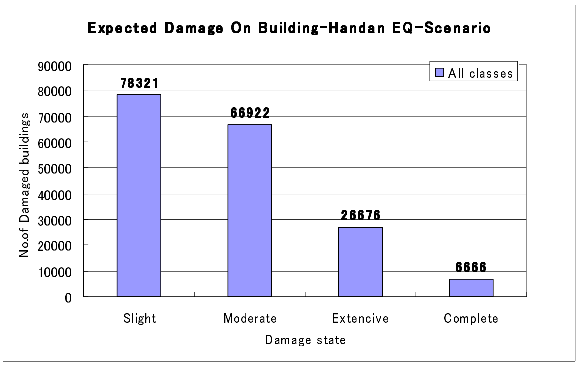
• Buildings located above soft sediments site have higher damage and more vulnerable to risk comparing to buildings located on hard rock

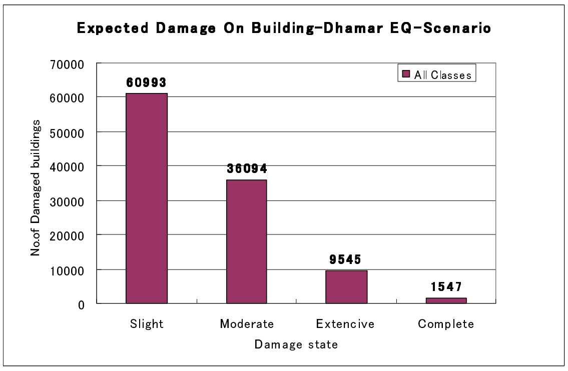
• Buildings having structural properties similar to URML model type is damaged more than RML type.

• The highest Spectral ground acceleration was (0.05-0.07g) for long period and (0.1-0.15g) for short period and located **at central part of Sana'a city**. Whereas maximum estimated seismic intensity around *VI*.

Discussion and Conclusions

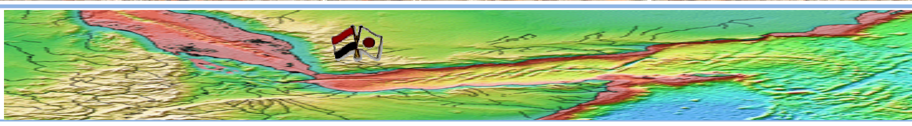
Expected damage on buildings





The structural properties of Yemini's buildings such as capacity, damage function, height of building ,exact number of buildings per district, population and location must be provided completely with accurate level in future work to get the more realistic results of risk evaluation of buildings in study area.

SVOC



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