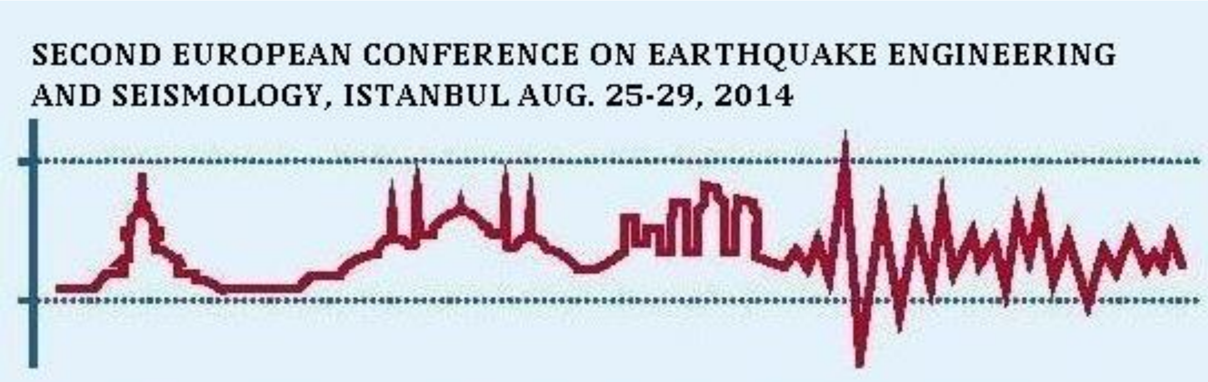

SEISMIC RISK ESTIMATION FOR WADI MUSA IN JORDAN

Viviana NOVELLI[1], Dina D'AYALA[2], Adel AL-ASSAF[3], Emad AKAWWI[4]

ABSTRACT

The seismic risk of the city of Wadi Musa (Jordan) is the work developed in the framework UNDP-JORDAN RFP/2012/19 project, coordinated by Dar Al-Omran Infrastructure and Environment, Amman and involving a multi-risk assessmnet of the city. The Wadi Musa's building stock is manly composed of reinforced concrete buildings classified in twenty different building typologies, which have been identified by using data collected on site, ortho-photo images and cadastral maps. Information regarding the repair costs of each identified building typologies and the day/ night time population have been also collected and provided by the Municipality of Wadi Musa. The capacity curves and fragility curves of the identified building typologies have been obtained from numerical nonlinear push-over analysis performed on geometric and mechanical parameters, representative of the constructions observed on site. The data collection activities have been accomplished within the timeframe and budget of the project; to overcome the lack of knowledge on structural details of specific building typologies, some assumptions have been made to improve the quality of the available information. The assumptions considered in this study and how these affect the estimation of the seismic risk of Wadi Musa are discussed and highlighted in this paper. Moreover, in the present work the limitations of using predefined vulnerability curves of the HAZUS (FEMA 1999) approach for Wadi Musa, characterised by a large variety of building typologies, is emphasized The assessment of the damage probability, the economic and the human losses has been performed by using Selena© and the results are mapped with ARCGIS ©.

INTRODUCTION

Currently probabilistic assessment of seismic risk represents the state of the art tool used for quantifying damage probability and economic/human losses of seismic prone areas and for proposing mitigation measures to reduce such risk. The results are usually conveyed by producing GIS maps where the probability of exceedance for a given damage state or economic or human loss is provided per unit of geographical surface, geo-unit.

In order to perform such assessment, data about building typologies, soil condition, earthquake sources, attenuation relationships, ground motion amplification factors, repair or replacement costs and population of the area under study, is required to estimate all types of vulnerability due to the seismic hazard. In order to produce such assessment all data needs to be geo-referenced. Increasingly national and regional government are requested to adopt such instruments, if they are to obtain international development grants and investments. In this paper the issues, which might occur, in case

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the collected data for a region are not sufficient or incomplete, are presented, and the assumptions, which can be taken to overcome the lack of data, are discussed.

In particular, these specific issues have been analysed in the present work by means of the tasks within the UNDP-JORDAN RFP/2012/19 project, which has been funded to estimate the seismic risk of a city located in the Southern Jordan: Wadi Musa, of strategic importance to Jordan economic development as the Petra archaeological site comes under the city authority and it is arguably Jordan's heritage major touristic attraction.

Figure 1 shows the contribution and flow of the input data to the seismic risk assessment. The blue box collects the primary data required for the characterization of the area of study.

The information of the cadastral map and the aerial photography, census data, technical drawings of the buildings are provided by the Municipality of Wadi Musa. As highlighted by the red box in Figure 1 this have been have been combined, in order

- to classify the building stock of Wadi Musa according to the WHE-PAGER project taxonomy (Jaiswal et al. 2011),
- to define and to localize the most common building typologies,
- to model the building typologies and to define capacity and fragility curves.

In order to estimate the seismic capacity of the local building stock (red box in Figure 1), information regarding the seismic standards and code of practices, from their first version introduced in Jordan to its latest update, are required. This information together with an inventory of how many buildings are likely to have been designed according to the structural code (non-seismic) and of each edition of the seismic standards, allow a first definition of building typologies. This information can be obtained by analysing past and present cadastral maps, which report the year of constructions of the buildings, and knowing the historical development and enforcement of codes at the site. Furthermore, the classification and inventory of each building is influenced by the available economic/staff resources and time and the number and types of buildings within the urban context that can be surveyed.

The earthquake catalogue, the geology of Wadi Musa, soil maps and attenuations law were used to derive uniform hazard curves and provide probabilistic PGA maps for Wadi Musa, as it is illustrated in the green box of Figure 1. For this study two sismogenic sources the Dead Sea fault system, and the Aqaba gulf source system, have been considered. Spatial attenuation distributions were identified and two PGA scenarios for a 475 return period were produced alongside maps for three spectral accelerations, corresponding to three values of natural period.

The data related to the construction and repair costs, in the purple box of Figure 1, and the data related to the population distribution, turquoise box of Figure 1, are collected per typology and use of building, combined with the information on occupancy - to estimate its economic and human losses after a seismic event. The repair costs rate for the different building typologies in the area of study are based on local contractor experience in similar projects, while population distribution rates are obtained through the census data.

Once the building stocks have been classified according to criteria which are further discussed in the next sections, adaptive pushover analyses have been performed to estimate a capacity curve for each identified building type. This has been carried out by developing full 3D finite element models in Seismostruct ©, finite element analysis package (SeismoSoft, 2011). Consequently, fragility curves have been estimated and the damage thresholds for each building typology have been defined.

The above data has been used as input for SELENA © (Molina et al., 2012) to compute the damage probabilities for the identified building typologies, the economic losses and the casualty probability for injury level and time of day. The damage probability has been computed by using the improved displacement coefficient method (Molina et al., 2012) using the capacity curves and fragility functions derived for Wadi Musa within the present study, rather than the predefined capacity curves and fragility functions of HAZUS (FEMA 1999), available in SELENA. The estimation of the human and human losses is computed by using the HAZUS (FEMA 1999) approach (Coburn and Spence, 2002). The final results are mapped by damage probability maps, economic loss and human casualties using the ARCGIS © programme and overlaying the cadastral map to the geounit results so that specific vulnerable buildings which should be subjected to a more detailed checking can be clearly identified.

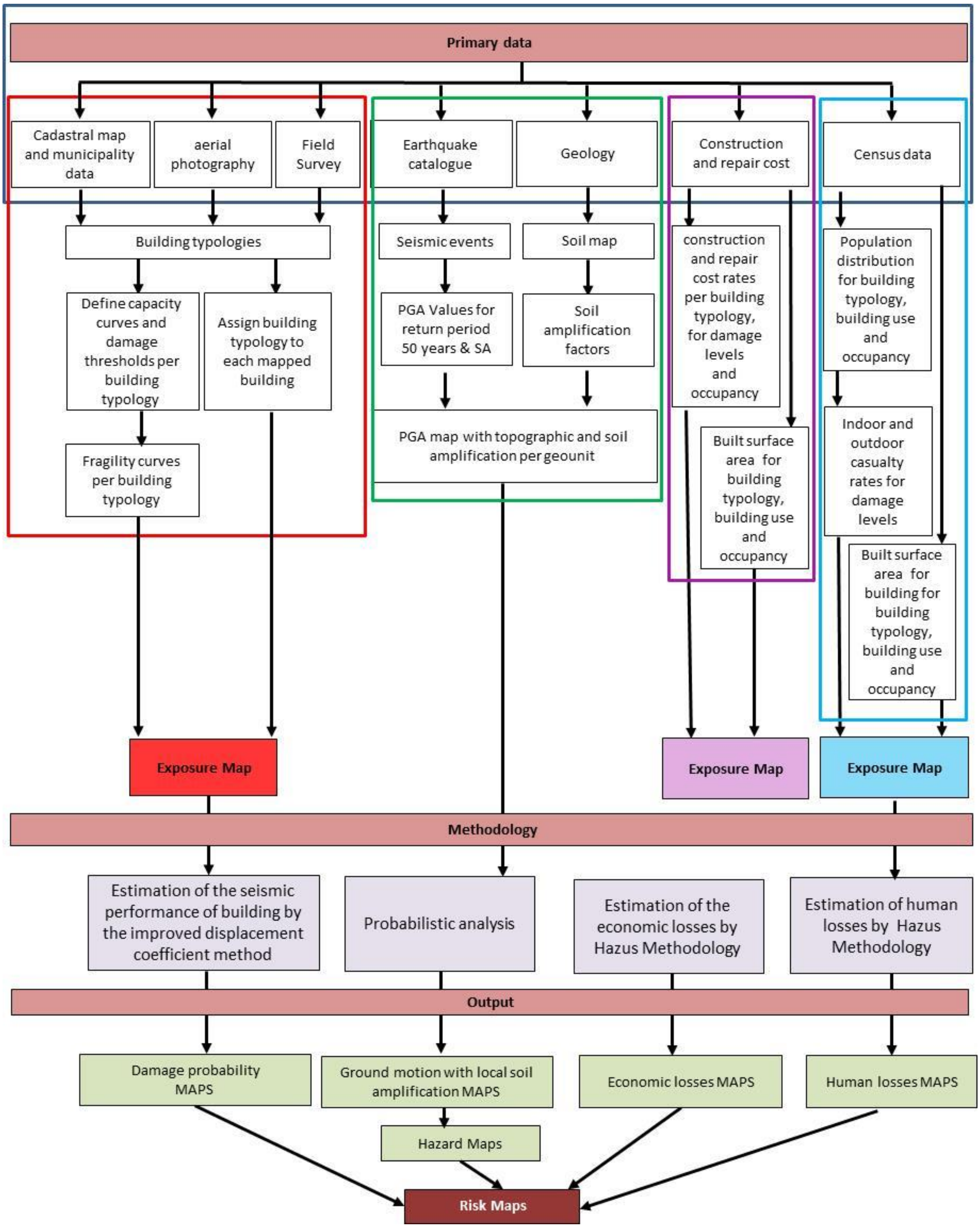


Figure 1: Flowchart for the estimation of the seismic risk

CLASSIFICATION OF BUILDINS BY TYPOLOGY AND SEISMIC DESIGN

The RC buildings in the town of Wadi Musa have been classified in three main categories: buildings with 1 and 2 storeys defined as low rise (L), buildings with 3 and 4 storeys as medium rise (M) and High rise (H) for buildings with more than 4 storeys. Within these three categories the following building constructions, observed during the preliminary survey carried out in March 2013, are identified: (C1L) Concrete bear frame; (C3L) Concrete infilled frame; (C4L) Concrete soft story; (C1M) Concrete bear frame; (C3M) Concrete infilled frame; (C4M) Concrete soft story and (C3H)

Concrete infilled frame. The age of construction, resulting in changes in standards, either by law or practice in the last 30 years, is taken into account by classifying the identified typologies as follows: (L) buildings pre year 2000 and (M) buildings post year 2000, where L and M stand for Low seismic and Medium seismic Code prescriptions respectively.

As masonry buildings are a very modest minority in Wadi Musa, with a maximum number of two floors and having been erected before the year 2000, only one class, named: URMLL, is defined.

The total building typologies identified for the city of Wadi Musa are 20. Their geometric and mechanical properties have been collected by using plans and documentations provided by the Municipality of Wadi Musa for 40 buildings of different heights, different foot prints and different period of construction.

According to available documentation from blueprints deposited in the Municipality Archives, buildings belonging to the classes pre' 2000, , are characterized by two main floor typologies: one way flat slabs or two ways flat slabs with a thickness of 120 mm. Buildings belonging to the classes post '2000, have one way ribbed slab of maximum 250 mm depth. The different types of horizontal structures are taken into account in the classification of the 20 building typologies identified in the area of Wadi Musa by creating classes of buildings with one way slab, which are labelled by (-1) and classes with buildings with two ways slab labelled by (-2). Other differences in buildings pre- and post- 2000 relates to nominal strength of concrete and steel reinforcement.

The typical floor height of the RC buildings provided by the Municipality is 3m. The infill panels for the classes C3 and C4 are in stone or in solid bricks. The soft storey (class C4) characterises buildings housing commercial activities at ground floors with light partition and large glass panels.

INPUT FOR THE COMPUTATION OF THE SEISMIC SCENARIO OF THE AREA OF WADI MUSA

The seismic scenario for Wadi Musa is computed by using the coefficient displacement method (DCM) of FEMA 365 (FEMA 356) with improvements proposed in FEMA 440 .

This will be referred as the improved displacement coefficient method (I-DCM), in agreement with the nomenclature used in the SELENA manual. However, rather than using the predefined vulnerability curves of the HAZUS (FEMA 1999) approach, available in SELENA, and given the substantial difference between the typologies identified in the area of study with respect to the existing HAZUS (FEMA 1999) typologies, specific capacity curves have been derived. These are of interest as they represent not just the building stock of Wadi Musa, but they are valuable at national and regional level.

For each basic typology capacity curves are derived considering the level of interaction with the infill and producing three alternatives: bear frame behaviour (C1), infilled frame (C3), and partial infilled (soft storey, C4). The corresponding models developed in Seismostruct © are shown in Figure 2.

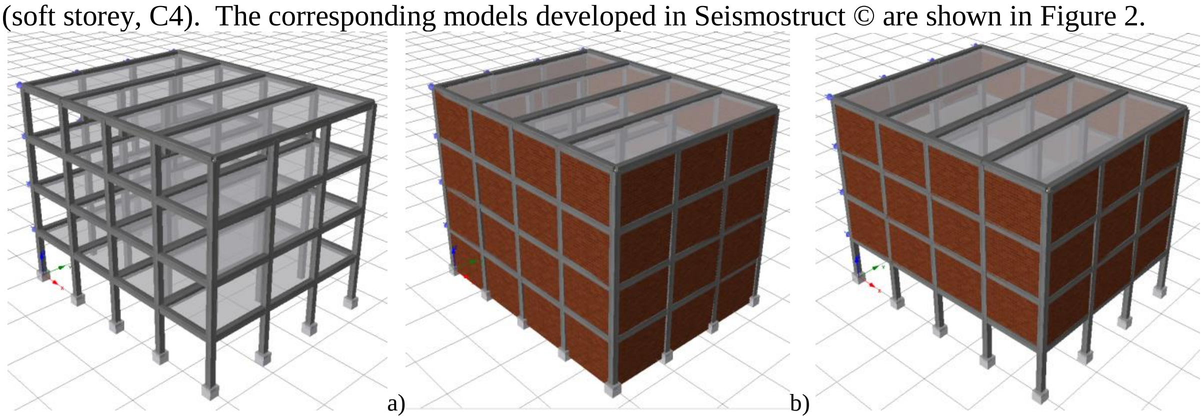


Figure 2: Numerical models implemented in Seismostruct © used to perform adaptive pushover analysis in x and y directions for pre '2000 buildings, with one way slabs, medium rise (four floors) belonging to classes: a) C1ML-1: bear frame, b), C3ML-1: infilled frame and c) C4ML-1.

Adaptive pushover analyses are performed in the two orthogonal directions and the minimum capacity curve obtained for each numerical model has been assumed as representative for the index building behaviour (Figure 3**Error! Reference source not found.**). This is conservative and appropriate to this level of risk analysis, considering that the quality of the data and the budget does not allow a greater number of index building models to be developed, to derive for each typology a statistically valid set of capacity curves. In order to validate and calibrate the approach followed, a comparison can be drawn with the available curves in HAZUS (FEMA 1999).

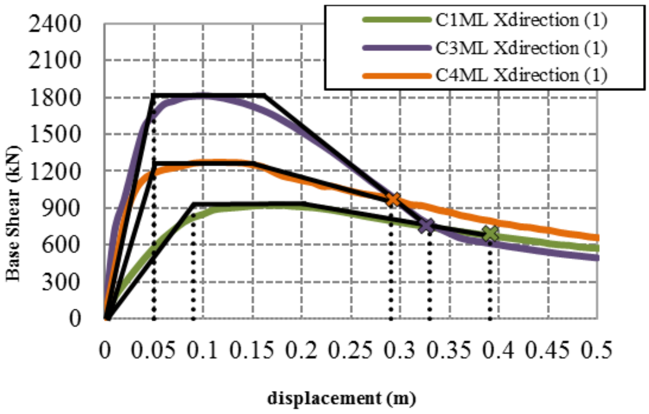


Figure 3: Push over in X direction and linearised capacity curves for pre '2000 buildings, with one way slabs, medium rise (four floors) belonging to classes: C1ML-1: bear frame, C3ML-1: infilled frame and C4ML-1: soft storey

Figure 4 compares the capacity curves of the building typologies pre' 2000 of medium height belonging to the classes C1 with one-way slab (1w_slab) and two-way slab (2w_slab) of Wadi Musa, and the predefined vulnerability curves of the HAZUS (FEMA 1999) approach for low and medium code for the same nominal typologies. This comparison highlights that the predefined capacity curves of the HAZUS (FEMA 1999) approach are not representative of the seismic behaviour of the constructions identified in the area Wadi Musa. Moreover, the softening in the capacity curves, which characterise the performance of the constructions in Wadi Musa, is not taken into account in the HAZUS (FEMA 1999) approach. The capacity curves of the buildings with one- or two-ways frames of the same class, although they have different seismic performance, as Figure 4 points out for the Jordanian buildings, are not diversified in the HAZUS (FEMA 1999) approach

Furthermore, in the HAZUS (FEMA 1999) methodology Class C4, defined in the present study as the class representative of the soft storey behaviour of reinforced concrete, is not included.

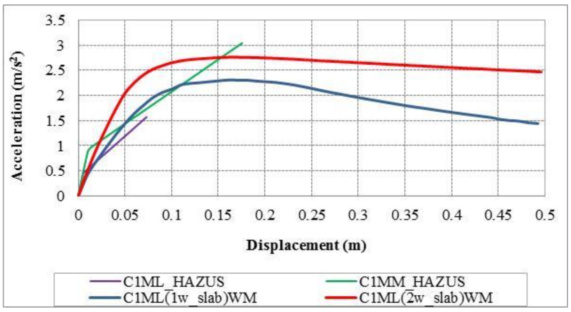


Figure 4: Comparison between the capacity curves computed on the geometric and mechanical properties identified in the area of Wadi Musa and the predefined capacity curves of HAZUS (FEMA 1999) approach

The next step is to compute fragility curves for each typology class. Fragility functions express the probability of a damage state, sustained by an examined building class, being reached or exceeded given a level of ground motion intensity measure. In this study S_d -based fragility curves, are developed using equation (1):

$$F\left(DS \geq ds_i \mid S_d\right) = \phi\left(\frac{1}{\beta_{ds_i}} ln\left(\frac{S_d(T)}{\overline{S}_{d,ds_i}}\right)\right) \tag{1}$$

where $\overline{S}_{d,ds_i}$ is the median value of spectral displacement at which the building reaches the threshold of damage state, ds_i. For nonlinear static-based fragility functions, $\overline{S}_{d,ds_i}$ is obtained from the capacity curve (i.e. S_a - S_d relationship) which is the reduced Force-Displacement relationship resulting from nonlinear static pushover analysis of a building. Each fragility curve is defined by a median value of spectral displacement that corresponds to the threshold of that damage state and by the variability associated with that damage threshold. Defining appropriate values for the damage state thresholds in terms of spectral displacement involves several uncertainties, related i.e. to the qualitative definition of the damage states, the assumptions used for inelastic analysis, and the shape of the derived pushover curve. In Figure 5 fragility curves for the Medium height low code typologies are shown for 4 damage states.

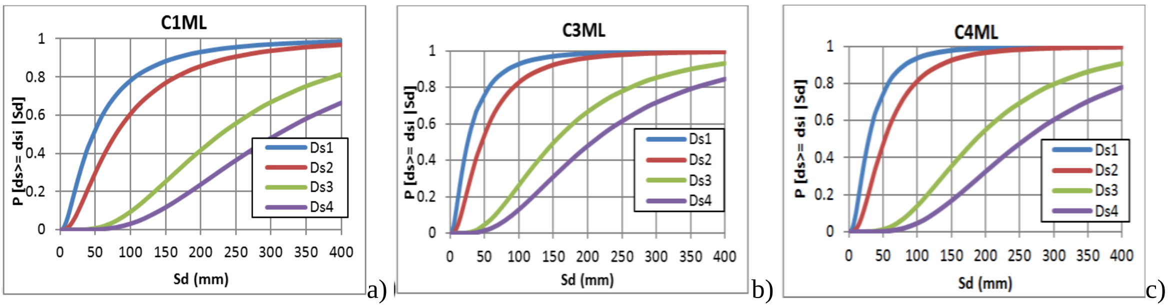


Figure 5: Fragility curves for pre ‘2000 buildings, with one or two way slabs, medium rise (four floors) belonging to classes: C1ML: bear frame, C3ML: infilled frame and C4ML: soft storey

The next step, once the structural performance of each building typology is defined in Selena, is to classify the 2831 buildings of Wadi Musa according to the identified building typologies. It was not possible within the timeframe of the project, to survey all buildings in the area of study and to attribute a typology accordingly; hence the classification is done on the basis of a number of assumptions relating to the available data.

The following information, available for all buildings in Wadi Musa and used for this purpose, is taken from the cadastral map of the area of study:

- Number of floors. This is used to classify the rise of the building. In particular it is excluded that infill panels affect the structural performance of buildings belonging to low rise class with only one floor and buildings belonging to medium rise with only three floors, therefore buildings with one floor and three floors are always classified in Class C1.
- Foot print of the building. This is used to classify the buildings pre 2000 with a foot print smaller than 200 sqm as one way slab (-1) and buildings pre 2000 with a foot print larger than 200 sqm as two way slab (-2).
- Use of the building. This is used as follows: in case the building has a commercial use this is always classified in class C4 (soft storey)
- Location of the buildings. This is used as follows: 20 % of buildings with two floors located in the down town of Wadi Musa, not used for commercial activities belong to class C1 and the rest to class C3.

INPUT FOR THE COMPUTATION OF THE SEISMIC RISK

The area of Wadi Musa has been divided in 818 geounits of 100x100m and for each geounit the pga and the spectral response accelerations for 1.0 second and 0.3 sec periods with a 10% probability of exceedance in 50 years have been estimated and used to calculate the seismic risk of Wadi Musa. The soil classification (Figure 6a) in the area of study has been performed according to the NEHRP (IBC-2006). The soil amplification factors, computed on the basis of the soil classification mentioned above, used by Selena to amplify the spectral acceleration, are mapped in Figure 6b.

Two different scenarios have been provided for Wadi Musa, one with seismogenic source the Dead Sea fault system, the other with seismogenic source Aqaba Gulf. The difference between the two scenarios in global terms is not substantial, the Sa at 0.3 sec is between 0.212 (g) and 0.231 (g) for scenario 1 and between 0.180 (g) and 0.250 (g) for scenario 2, shown in Figure 7a and Figure 7b respectively. However the distribution over the district varies, reflecting the different relative location of the site to the seismogenic source. The sites of new developments, located in the northwest of the city and closer to the World heritage site, where touristic facilities are built, are characterised by a slightly higher acceleration corresponding to T=0.3 s in both scenarios. Since the results obtained for the two scenarios are not substantially different, the maps reported and commented in the present paper refer only to the scenario 1.

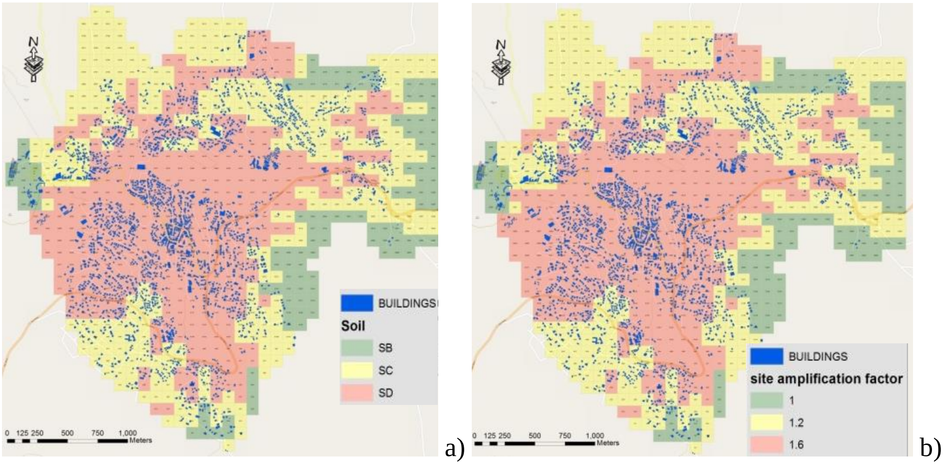


Figure 6: a) Soil classification of Wadi Musa b) Amplification factor for Wadi Musa

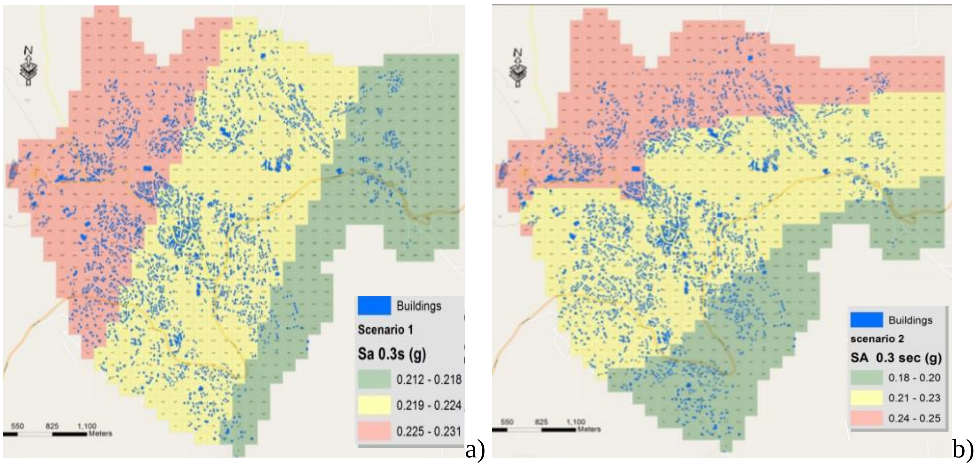


Figure 7: a) Spectral acceleration at 0.3 sec. Dead Sea b) Spectral acceleration at 0.3 sec. Aqaba

INPUT FOR THE COMPUTATION OF THE ECONOMIC LOSSES

The repair costs have been provided by Dar Al-Omran Infrastructure and Environment, and they are defined for residential constructions with a single occupancy, belonging to class C1 (bear frame).

As for the other building typologies identified in Wadi Musa, the repair costs have been estimated by applying modifying factors to the available costs by taking into account the occupancy and the use of the buildings. The cost are defined are defined for different damage states (from slight damage to complete damage).

INPUT FOR THE COMPUTATION OF THE HUMAN LOSSES

The total population of Wadi Musa and the population per night time and per day time have been provided by Statistics Department of Jordan on the basis of the census published in 2012. Moreover, the Ministry of Education has recently required a counting of the number of students per school, which has been taken into account in the present study. As for the number of tourists in Wadi Musa, this is estimated on the recent estimation released by the Ministry of Tourism.

The data, as mentioned above, has then been redistributed according to the use of the buildings identified in the area of study.

Table 1 reports the total population distribution of Wadi Musa, the total population per night time and day time for residential buildings and the total population for the following buildings uses: commercial and industrial activities, schools and hotels. Moreover, it also provides the number of people commuting the city of Wadi Musa.

Table 1: total population

Description	Population
POPULATION:total census tract population,	18541
DAYTIME_RES:day time residential population inferred from census data,	3895
NIGHTIME_RES: night time residential population inferred from census data,	16133
COMWRK: number of people employed in the commercial sector,	8612
INDWRK: number of people employed in the industrial sector,	9
COMM: number of people commuting inferred from census data,	12839
GRADEPOP: number of students in grade school (under 17 years old),	3891
HOTELPOP: number of people staying in hotels in the census tract.	1683

LIMITATIONS OF THE PRESENT STUDY

The cadastral maps reports that only 1.13% and 0.14% of the total number of buildings in the area of study have 4 floors and 5 floors respectively, and almost 60 % of buildings have only 1 floor. This is in contrast to the information collected on site and the recent pictures taken during the surveys which show many buildings with 4 floors and in some even with more than 5 floors.

The floor number of each building reported in the cadastral map is information gathered from the construction permits, available from the Municipality of Wadi Musa. However, since, for most of the buildings in the area of study, new floors have been illegally added, their construction permit still reports the original number of floors, for which the buildings were initially designed to. This explains the inconsistency between the data collected from the cadastral map and by visual inspections.

In order to take into account this discrepancy the following assumptions have been made:

- the performance of buildings with one floor pre and post ‘2000 have been represented by the capacity curves developed for index buildings with two floors,
- the performance of buildings with three floors pre and post ‘2000 have been represented by the capacity curves developed for index buildings with four floors
- the performance of buildings with five floors pre and post ‘2000 have been represented by the capacity curves developed for index buildings with 6 floors

As consequence of this, the foot prints in the cadastral maps also refer to the number of floors of the construction permits, therefore the damage probability and the economic and human losses are also affected by this approximation.

A second limitation in the present work, although most of the buildings in Wadi Musa are regular in plan and elevation, consists in modelling irregular buildings by using numerical models which are regular in plan and elevation (as the ones in Figure 2). However, this simplification is a reasonable and common assumption, as irregular buildings tend to represent a minority of a building population. The results obtained by the present study are affected by the following assumptions which are associated with data limitations:

- Estimates of a realistic number of storey per building.
- Estimates of total surface area per building
- Estimates of building typology attribution
- Estimates of population density for different occupancy type of building
- Estimates of repair costs for different damage level and occupation type

Conversely elements that improve the reliability of the study are the relatively accurate modelling of the local building types, considering a substantial sample of prototypes and producing a sufficiently varied number of typologies. This approach has also allowed the derivation of study specific fragility curves for each typology and for four different levels of damage. For ach fragility curve the beta factor has also been calculated taking in to account the sensitivity of the response to the quality of the material as obtained by the pushover analysis.

DAMAGE PROBABILITY

The results of the damage probability for each building typology identified for Wadi Musa produced by Selena are summarized in Table 2. The table reports the damage probability in terms of percentage of the total number of buildings for each identified building typology. The damage probability is determined for the five damage levels defined in HAZUS (FEMA 1999) (FEMA 1999).

These results are produced on the basis of the limitations discussed in the previous section and the information on the building stock of Wadi Musa provided by the Municipality. This means that a re-assignment of the more accurate number of storeys for each building will warrant a re-calculation of the damage probability reported in Table 2. However these results are still valid in terms of relative vulnerability between building typologies.

Table 2: Damage Probability Summary

building typology	no damage	slight damage	moderate damage	extensive damage	complete damage	total number of buildiungs
C1LL-2	0.29	0.27	0.42	0.01	0.00	171
C1LL-1	0.57	0.28	0.16	0.00	0.00	1068
C3LL-2	0.28	0.27	0.45	0.01	0.00	272
C3LL-1	0.24	0.32	0.44	0.00	0.00	477
C4LL-2	0.62	0.26	0.12	0.00	0.00	79
C4LL-1	0.21	0.31	0.48	0.01	0.00	247
C1ML-2	0.38	0.23	0.37	0.02	0.01	54
C1ML-1	0.38	0.26	0.35	0.01	0.00	38
C3ML-2	0.45	0.24	0.30	0.01	0.00	15
C3ML-1	0.30	0.13	0.57	0.01	0.00	3
C4ML-2	0.32	0.26	0.40	0.01	0.00	14
C4ML-1	0.30	0.13	0.56	0.01	0.00	20
C1LM	0.47	0.26	0.26	0.01	0.00	220
C3LM	0.37	0.30	0.31	0.01	0.00	108
C4LM	0.35	0.22	0.32	0.04	0.07	20
C1MM	0.33	0.25	0.35	0.05	0.03	11
C3MM	0.19	0.36	0.43	0.01	0.01	2
C4MM	0.17	0.33	0.47	0.02	0.01	5
C3HL	0.15	0.25	0.47	0.10	0.03	6
URMLL	0.78	0.14	0.08	0.01	0.00	1

Table 2 shows that most of the buildings have moderate damage, for the given scenario, which means they would in general be repairable. However it might be more cost effective to implement strengthening and retrofit as a mitigation policy.

The map in Figure 8a points out that the class C1LL-1, reinforced concrete frame of 1 or 2 floors with one way flat slab, built before 2000, has a probability of moderate damage between 10 and 40%. This damage probability increases with the class C3LL-1, infilled reinforced concrete of 1 or 2 floors with one way flat slab as it is indicated in Figure 8b, where the percentage of damage is between 40% and 50% for the same level of damage. The class C1ML-2, in Figure 9a, which represents the reinforced concrete frame of 3 or 4 floors with two ways flat slab has a higher of probability of moderate damage than the class C1LL-1 and C3LL-1, which is between 20% and 60 % of the total number of buildings classified in this category. The class C4MM, which represents the buildings with commercial activities with 3 or 4 floors built after 2000 with one way ribbed slab, has a 50% of probability of moderate damage. For extensive and complete damage, as it is highlighted in Table 2 and in in Figure 9b, the probability of damage are very low (order of 5%) even for the building typologies with the highest probability.

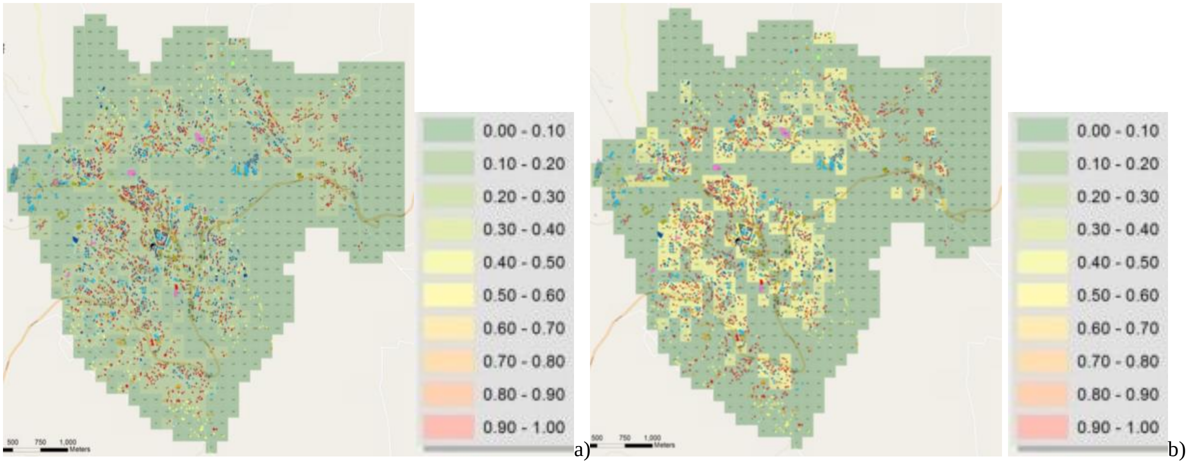


Figure 8: a) Damage probability for class: C1LL-1 moderate damage, b): Damage probability for class: C3LL-1 moderate damage

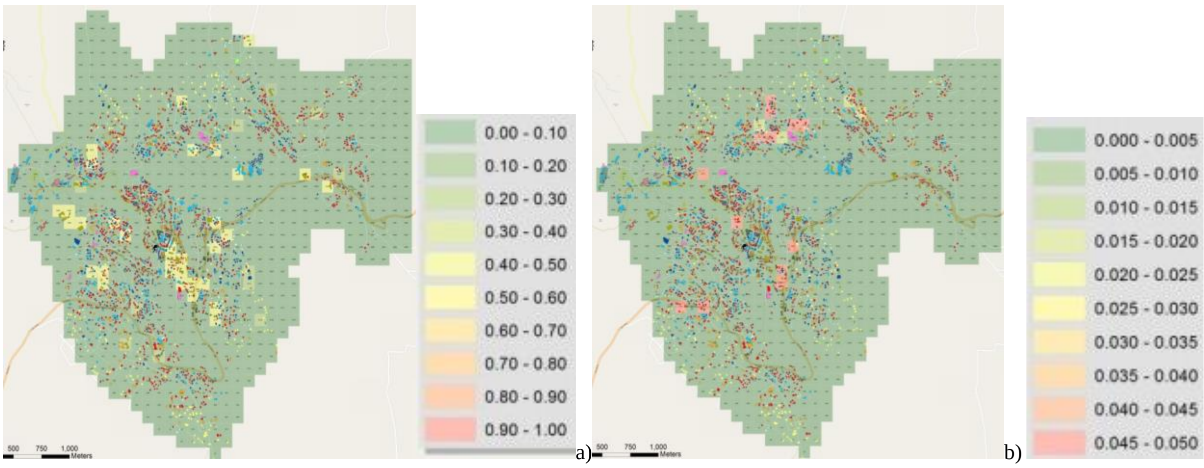


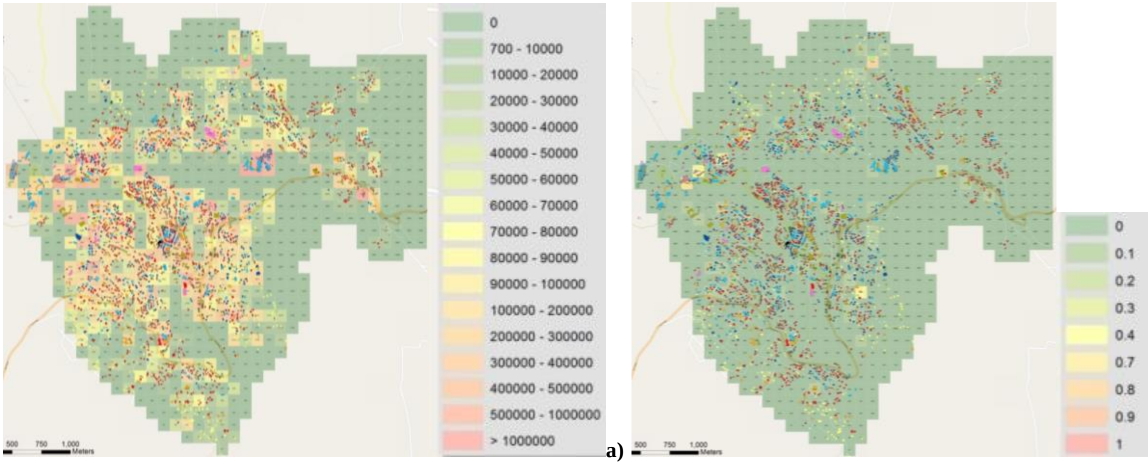
Figure 9: a) Damage probability for class: C1ML-2 moderate damage, b) Damage probability for class: C4LM extensive damage

ECONOMIC AND HUMAN LOSSES

The economic losses is illustrated in Figure 10a. The results show that the repair costs are between a minimum cost of 700 JDT/geounit to a maximum cost above 1m JDT/geounit.

The human losses is computed at three different times: 2:00 am, 10:00 am and 5:00 pm

Since most of the buildings have suffer a probable moderate damage, the probability of injured people is also very low, as shown the map in Figure 10b related to the injured people at 2:00 am, Although hours of business for commercial and administrative activities are different in Jordan is different from working pattern tin Europe or US, the reference time 5:00 pm which represents the closing time of the commercial activities in Europe and US, in the present case of study refers to 8.00 pm, closing time of the commercial activities in Wadi Musa.



a) b)

Figure 10: a) economic losses b) injured people at 2 am

CONCLUSIONS

The present work carried out for the Wadi Musa on the basis of the data collected from cadastral maps provided by the Municipality has shown that most of the buildings have either no damage or a moderate damage for both scenarios based either on a seismic source in the Dead Sea region or in the Aqaba region.

The building classes that appear most vulnerable represent buildings built after 2000, and classified as medium capacity code. This reflects the introduction of the new building code in Jordan, along the lines of the US UBC code, which recommend the use of materials with higher strength class and ductility than the materials recommended in the previous code and used up to the year 2000. These results, which may appear surprising, since even the fragility curves obtained for the classes post 2000 have thresholds which are higher than the threshold identified for the classes pre 2000, can be explained by the heavy slab used in the constructions built after 2000 which correspond to a substantial increment in mass, not met by a corresponding increment in lateral capacity by the frame system. The results highlight the following trends:

- The most common building type is low rise low cost, one way frame, which is also the most resilient, with 56% probability of no damage. However if, as probable, a consistent proportion of these buildings has 3 to 4 floors in reality then their probability of moderate damage may increase to more than 30%.
- The Low rise, soft stories post 2000 building typology (C4LM), representing commercial buildings, is associated with the greatest loss. To this class currently is associated a modest proportion of the building stock, however the loss could be greater if with a higher number of storeys.
- Similar results as the previous point are obtained for medium rise post 2000 bear frame (C1MM)
- The probability of collapse or extensive damage is negligible for most building classes except for two building types: C4LM and C1MM, in total affecting 30 buildings, however with cumulative probability of exceedance between 3% and 7 %.

- There is a substantial scatter in economic losses per geounit, from a minimum economic loss of 0 JDT per geounit to a maximum economic loss greater than 1.0 M JDT per geounit. The higher losses per geounit are associated with building typology C3LL-1 and C3LL-2.
- The casualty study shows that given the level of physical damage, the probability of deaths is 0.
- The highest probability of injured losses is at 2:00 am as it should be expected considering that the most common use is residential
- The most common injured level is LOW at 2:00 am
- However at 17:00 the MEDIUM injured level is 10% probability reflecting the enhanced fragility of some of the commercial buildings highlighted above.

REFERENCES

ATC 58 (FEMA P-58) – Seismic Performance Assessment of New Buildings + ATC 86 – Environmental Assessment

ATC-13 Earthquake damage evaluation data for california. Technical report, Applied Technology Council (ATC), Redwood City, California, 1985. Report ATC-13.

ATC 63, ATC 76-1, ATC 76-4, and ATC 84 – Related to FEMA P-695 and FEMA P-795

ATC-40 Seismic evaluation and retrofit of concrete buildings. Technical report, Applied Technology Council(ATC), Redwood City, California, 1996. Report ATC-40.

Coburn A, Spence R (2002) "Earthquake protection." J. Wiley and sons Ltd

D'Ayala D., Meslem A., Vamvatsikos D., Porter K., Rossetto T., Crowley H., Silva V. (2014)"GEM Guidelines for Analytical Vulnerability Assessment of Low/Mid-rise Buildings" Publisher: Global Earthquake Model

HAZUS (1999) Earthquake loss estimation methodology—technical and user manuals, vol. 1–3. Federal Emergency Management Agency (FEMA), National Institute of Building Sciences, Washington, DC

Jaiswal K., Wald D, D'Ayala D (2011) "Developing Empirical Collapse Fragility Functions for Global Building Types" Earthquale Spectra, Volume 27, Issue 3

Molina S., Lang D. H., Lindholm C. D., Lingvall F. and Erduran E. (2012) "User Manul for the Earthquake Loss Estimation Tool: SELENA v6.0

Molina S., Lang D.H., Lindholmb, C.D. (2010) "SELENA – An open-source tool for seismic risk and loss assessment using a logic tree computation procedure" Computers & Geosciences. Volume 36, Issue 3, March 2010, Pages 257–269

Park, Y. J. and Ang, A. H. S. (1985) "Mechanistic seismic damage model for reinforced concrete" Journal of Structural Engineering, ASCE 111(4), 722–739.

SeismoSoft (2011). SeismoStruct – A computer program for static and dynamic nonlinear analysis of framed structures.