

# GIS APPLICATION FOR SEISMIC HAZARD ESTIMATION FOR A BURIED STRUCTURE

# Ali Naiieri<sup>1</sup>, Mohammad Taqi Mohebbi<sup>2</sup>

### SUMMARY

Seismic hazard estimation comprises a basic step for design of engineering structures in earthquake prone areas. Among several parameters of strong ground motion, peak ground acceleration (pga) is the most popular and widely used parameter for design

When studying the seismic hazard for an extended site, like a pipeline, one is faced with a series of sites oriented along the pipeline, instead of a single site. This spatial relation is in favor of GIS applications.

In this study, a probabilistic approach was applied for seismic hazard estimation. Pga values were estimated along an extended buried pipeline using GIS applications. Pga profile was queried out from a raster Digital Elevation Model (DEM), specifically generated for this purpose. The accuracy of the estimation was further enhanced using digital image processing techniques. Results were cross-checked with pga-estimates obtained by routine probabilistic hazard analysis at certain fixed sites along the pipeline. The estimation error was less than 10%, which is reasonably acceptable from engineering point of view.

For the methodology introduced in this study, it is not necessary to know the final route of the pipeline, *a priory*, while in routine single-site based analysis, this information is a crucial assumption. The mentioned point considerably speeds-up the hazard analysis in such cases where there are several alternatives for the route. In fact, the technique presented here enables the engineering seismologist to start the analysis at early stages of the project.

<sup>&</sup>lt;sup>1</sup>Chief Engineering Seismologist, Lar Consulting Engineers, Tehran, Iran, Email: <u>anaiieri@yahoo.com</u>.

<sup>&</sup>lt;sup>2</sup>General Manager, Lar Consulting Engineers, Tehran, Iran, Email: mohebbi@lar-co.com

#### **INTRODUCTION**

Seismic hazard estimation comprises a basic step for design of engineering structures in earthquake prone areas. Among several parameters of strong ground motion, peak ground acceleration (pga) is the most popular and widely used parameter for design from early steps in feasibility studies to the final design. The parameter is normally estimated for a single site at three seismic levels for design, say, Design Basis Level (D.B.L.), Maximum Design Level (M.D.L.) and Maximum Credible Level (M.C.L.).

In a typical routine seismic hazard study, probabilistic analysis is carried out using three main categories of potential earthquake sources, that is, seismic point-, line- and area-sources. Depending on the type, importance, cost, lifetime, and unfavorable outcomes of possible failure of the concerned structure, an appropriate acceptable risk and level of conservatism is considered for the analysis.

A continuous structure with finite dimensions, such as a tunnel or pipeline, may be considered as spatially distributed single sites oriented close to each other along the extended structure. In routine practice for such an extended structure, seismic hazard analysis is carried out for a number of discrete sites along the structure. However, it is practically not feasible to make a continuous pga profile along the route by routine approach. The close spatial relation between adjacent points along the project line is in favor of a raster-based analysis by GIS applications. The objective of this study is to demonstrate how GIS helps rapid extraction of design parameters for a number of existing alternatives, using a DEM model developed for this purpose. Site effects are not considered for this demonstration, but could be neglected for tunnels built within hard rocks.

#### 2. Study area

The study area is located in central Iran (Figure 1), between northern latitudes 33.5-34.2 and eastern longitudes 49.1-49.8 degrees. Main scope of the project is to transport water from the Kamal Saleh storage dam in the south to the city of Arak in the north, via a pipeline with a length as much as about 80 km.

In the early stages of the investigations, four possible routs were suggested for water conveyance. These are tabulated below, and shown in Figure 2.

No.	Route name	Code	
1.	AL. I	ABCDE	
2.	AL. II	ABCHDE	
3.	AL. III	ABF3GHDE	
4.	AL. IV	ABF4GHDE	



Figure 1. The study area

Among several proposed possibilities, the route IV has been considered as the most appropriate route in previous studies (Lar [4]). In this study, main concentration is on this route. However, thanks to the GIS techniques, the results could be extended to any other possible routes within the study area, as well.

# 3. Methodology

Hazard estimation has been performed using probabilistic analysis of seismic line- sources. The methodology proposed by Bender [1] was used for this purpose.

The results of the seismotectonic studies for the Kamal-Saleh storage dam (Lar [4]) was used for modeling capable faults (Figure 3). On the basis of the same report, average focal depth of earthquakes was considered to be 18km.



Figure 2. Schematic of several proposed alternatives for the pipeline (LAR [4]).

Seismicity parameters were obtained for an area of 200km from the Kamal-Saleh dam, using maximum likelihood estimation method (Kijko [3]). In this study, 20<sup>th</sup> Century and pre-20<sup>th</sup> Century earthquake catalogues were considered as the complete and extreme files of earthquakes, respectively. This method is also capable of considering different magnitude errors for both catalogues. The results obtained are as follows:

 $\beta = 2.26 (\pm 0.18)$  $\lambda = 0.41 (\pm 0.06)$ 

Seismic potential of potentially active faults was estimated based on the fault dimensions and past seismicity of the region, using the experimental relations suggested by Wells [5]. Standard error of estimates was considered in the analysis to obtain conservative 84% results.

Due to the seismotectonic sitting and low hazard level of the areas close to the pipeline, Design Basis Level was considered at a return period of 100 years. All pga's were computed using 50 percentile values of the Campbell [2] attenuation curve.

In this study, two approaches were followed: the routine analysis and the GIS-based analysis.



Figure 3. Simplified fault map of the study area (Lar [4])

# 3.1. Routine Analysis

In routine analysis, it is necessary to know the final route of the tunnel, *a priori*. The route IV was selected for this purpose. The 80km long route was subdivided into 16 target points, each about 5km apart. (Figure 4). Since the pipeline route is not regular in shape, the points were irregularly distributed in plan.



Figure 4. The pipeline route.

Routine seismic hazard analysis was performed for each target point. In this way, pga's were estimated at discrete points (P1 to P16, with P1 at the north-east end) along the line. Details of the methodology could be found elsewhere (Lar [4]). Results are presented in Figure 5 and Table 1.



Figure 5. Return period of pga at 16 target points along the pipeline, by routine analysis.

pg a	p1	p2	р3	p4	p5	p6	р7	p8	p9	p10	p11	p12	p13	p14	p15	p16
0.02	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
0.04	3	3	3	4	5	6	7	8	7	5	4	4	5	5	4	4
0.07	4	7	7	12	15	17	19	22	20	11	8	8	12	14	12	7
0.09	6	17	20	33	46	46	52	64	56	25	17	17	36	54	32	14
0.11	12	43	61	96	140	132	149	192	163	60	37	39	110	246	90	30
0.13	23	121	197	293	457	428	483	629	524	158	85	96	361	1257	273	64
0.15	47	377	656	949	1640	1534	1728	2263	1863	439	206	254	1301	6826	903	144
0.18	100	1252	2216	3195	6298	5894	6629	8703	7110	1283	521	714	5011		3149	335
0.2	222	4287	7539							3905	1377	2110				807
0.22	512										3746	6462				1999
0.24	1216															5047
0.26	2940															
0.29	7207															

Table 1. Pga estimates (g) for various return periods at points P1 through P16 along the pipeline

## 3.2. GIS-based analysis

In the GIS approach, the study area was divided into a regular grid of points, containing 110 nodes oriented regularly along 10 parallel north-south directed lines (Figure 6). This results to a mean cell size of 555 \* 707 square meters (representative of the metric X and Y cell dimensions, respectively).



Figure 6. Regular grid for pga estimation.

Line-sources were modeled and analyzed to obtain peak horizontal ground acceleration (pgha) at each grid node, using the probabilistic approach proposed by Bender [1]. Site condition was considered as rock type, for this illustration.

In the next step, a Digital Elevation Model of peak ground horizontal acceleration was generated. For this purpose, a moderate resolution (200\*220 pixels) mathematical surface was developed as a raster image, by interpolating pga-values between adjacent grid nodes with a 6-point search radius. As the lateral changes of the estimated pga values were relatively small, this ensures a reasonable estimate of the concerned parameters. A distance-weighted average approach was adopted with a distance weight exponent of two. In this way, a weight equal to the reciprocal of the distance squared is reached, which is more consistent with the distance-dependent attenuation of ground motion. The obtained DEM model is presented in geographic coordinate system (Lat-Long) in Figure 7.



Figure 7. DEM model for pgha in the study area. Faults shown as thick lines.

In this figure, pga-values vary from 0.04g (dark area north-west part of the figure), to 1.10g (white area in the south-east part). The last point with high pga-value is very close to the nearby contributing

active fault. Also shown is the route of the pipeline on the grid, as well as the 16 target points along the pipeline.

A comparison was made between the estimates of pga by routine analysis and GIS. For this purpose, two different approaches were adopted.

In the first approach, a semi-continuous pga-profile was queried out from the DEM image, showing pga-values along the pipeline, as presented in Figure 8. In this figure, the distance in horizontal axis has been inverted from the ratio of the total length of the profile-line (81km) to the total number of pixels along the profile (247), resulting to a mean pass-length per pixel of about 328 meters.



Figure 8. pga-profile along the pipeline, by GIS approach

Figure 9 shows the same pga-profile overlaid with the pga-values computed for the target points along the pipeline. Results have been presented in Table 2. However, there is a bias in distance estimate, which indicates the reduced accuracy of distance estimates in this approach.

In the next, more appropriate approach, image processing techniques in GIS application were applied to improve the accuracy of distance estimates. To do this, an INITIAL image was generated based on the Z-values of the DEM model. The 16-points p1 to p16 were then overlaid visually as a vector entity over the DEM model and were re-digitized as a new set of points. A single value of 1 was assigned to all



Figure 9. A comparison between the results of GIS-approach (line) and RA- approach (circles).

Table 2. Difference betwee	en pgha estimat	es by GIS- and
----------------------------	-----------------	----------------

Target Point	Δpga (GIS-RA)
p1	-0.02 g
p2	0
p3	0.02
p4	0.01
p5	-0.01
p6	0.01
р7	0
р8	-0.01
p9	0
p10	0
p11	0.01
p12	0
p13	-0.01
p14	0
p15	0.01
p16	0

RA- approaches

points. A raster image was then generated based on the INITIAL image and the set of digitized points. Finally, this raster image was multiplied digitally by the DEM model. In this way, all pixel values were set to zero except those containing the target points p1 to p16, for which pixel values were the respective pga values.

Figure 10 and Table 3 show the results. Deviation of pga estimates between GIS-approach and routine analysis at the target points are remarkably negligible from engineering point of view, indicating the applicability of the proposed approach for similar practical experiments.



Figure 10. Estimation differences between routine analysis (RA) and GIS approaches.

16-points	RA	GIS	∆pga (GIS-RA)
p1	0.18	0.16	-0.02 g
p2	0.13	0.134	0.004
р3	0.12	0.128	0.008
p4	0.11	0.119	0.009
р5	0.1	0.09	-0.01
p6	0.1	0.111	0.011
р7	0.1	0.104	0.004
p8	0.1	0.095	-0.005
p9	0.1	0.1	0
p10	0.12	0.122	0.002
p11	0.13	0.138	0.008
p12	0.13	0.136	0.006
p13	0.11	0.101	-0.009
p14	0.09	0.092	0.002
p15	0.11	0.116	0.006
p16	0.14	0.14	0

Table 3. A comparison between RA and GIS approaches.

# 5. Conclusion

- 1. Results of GIS application are reasonably accurate in comparison with routine analysis, provided the grid resolution in DEM model is sufficiently high. There is a trade-off between the resolution of DEM model and the practically acceptable margins for pga tolerance; the higher the acceptable tolerance, the lower the DEM model resolution.
- 2. In GIS, a reasonably continuous pga profile could be developed along the buried extended structure, while in routine analysis, pga is estimated for limited number of discrete points.
- 3. When the DEM model is developed for the study area, pga could be estimated along any given routes within the area in a fast way. Pga at over ground sites (like pumping stations, etc.) could also be estimated, provided the effect of the local site condition is within the acceptable tolerance, or is considered in the initial analysis.
- 4. In the proposed methodology, it is not necessary to know the final path of the buried extended structure, *a priory*, while in routine analysis, it is a crucial assumption. This considerably speeds-up the application of GIS in comparison with the routine analysis. In fact, GIS works could be started as soon as the general scope of the project is defined.

### REFERENCES

- 1. Bender ,B. and Perkins, D.M. "SEISRISK III, A computer program for seismic hazard estimation" U.S. Geol . Surv. 1987,Bull. 1772.
- Campbell, K.W. "Empirical near-source attenuation relationship for horizontal and vertical components of peak ground acceleration ,peak ground velocity, and pseudo absolute acceleration response spectra" Seismological Research Letters 1997; 68(1); 154-179.
- 3. Kijko, A. and Selevolle, M.A. "Estimation of earthquake hazard parameters from incomplete data files. Part II: Incorporation of magnitude heterogeneity", B.S.S.A. 1992; 82(1); 120-134.
- 4. Lar Consulting Engineers " Seismotectonics and seismic hazard analysis for Kamal-Saleh dam site", Internal Rep. 1997.
- 5. Wells, D.L. and Coppersmith, K.J. " New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement", B.S.S.A. 1994,84, 974-1002.