In this section, the shallow landslide is considered for the following reasons:

1) The onset of a shallow landslide occurs immediately and it is impossible to evacuate after commencement. Therefore, the potential of this hazard must be understood.
2) This type of hazard is considered remarkable in Algiers.
3) In general, countermeasures for remarkable landslides or high potential debris flow areas are basically the same as those implemented against rain and as have been implemented by other projects.
4) Concerning a debris avalanche, high land and steeply sloping topographic areas are basically at high risk. Although it is impossible to predict the future locations, the possibility of them occurring in shallow landslide zones is high.

The shallow landslide is caused largely by the unstable soil on the slope, the slope angle, geotechnical properties and seismic motions.

5-5-2 Methodology

As previously discussed, two types of slope are generally found, these being steep or gentle. The type is dependant on the geology; Schist and Calcareous sandstone generally form a steep slope and the other is gentle. The former is expected to result from a collapse and the latter from a land slide.

Therefore, 'mi' and 'p2l' are assessed based by Wilson's method while the other engineering geology is assessed by Siyahi's method.

(1) Principal

1) Method proposed by Wilson et al.

Wilson et al. (1979) assumed that in a thin layer, as shown in Figure 5-28, sliding occurs due to inertial loading. Equating sliding and resisting forces gives:

$$a_c = g\left[\frac{c}{\gamma \mathrm{h}} + (\cos\theta \tan\phi - \sin\theta)\right] \quad \text{.......... (5.1)}$$

where
ac: critical acceleration including the slide
g: acceleration of gravity
c: cohesion of soil
γ: unit weight of soil
h: thickness of the sliding layer
θ: angle of slope
ϕ internal friction angle of the layer

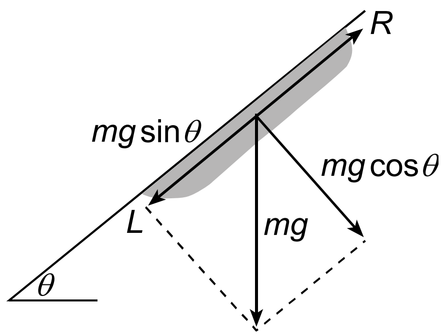


Figure 5-28　Model of Potential Landslide Mass (Tanaka, 1982)

Given the distribution of slope angle, the strength parameter c and ϕ, and lateral acceleration, the prediction of the distribution of slope vulnerability can be made.

2)　Method proposed by Ansal and Siyahil

Ansal and Siyahi (1994) developed a zoning method for slope instability by modifying a method proposed by Koppula (1984).　The method originally proposed was a pseudo-static evaluation of slope stability utilizing a seismic coefficient A to account for the earthquake induced horizontal forces.　The variation in shear strength with depth is assumed to be linear and the potential failure surface is taken as a circular arc as shown in Figure 5-29.

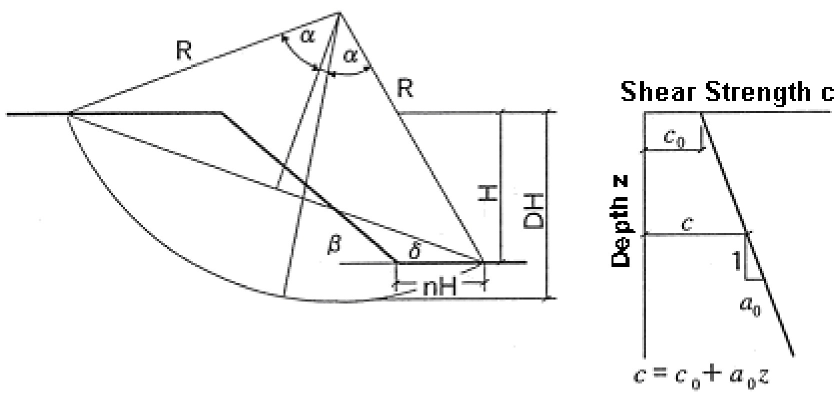


Figure 5-29　Typical Section of Slope (Koppula, 1984)

Parameters α, β, δ, and n are related to the geometry of the slope and the configuration of the sliding surface.　As given below, the safety factor, Fs, can be defined as :

$$Fs = \frac{a_0}{\gamma} N_1 + \frac{c_0}{\gamma H} N_2 \quad (5.2)$$

where,

$$N_1 = \frac{3(\alpha + \cot\delta - \alpha\cot\alpha\cot\delta)}{\sin^2\alpha \cdot \sin^2\delta(D_1 + D_2)}$$

$$N_2 = \frac{6\alpha}{\sin^2\alpha \cdot \sin^2\delta(D_1 + D_2)}$$

$$D_1 = 1 - 2\cot^2\beta - 3\cot\alpha\cot\beta + 3\cot\beta\cot\delta$$
$$+ 3\cot\delta\cot\alpha - 6n\cot\beta - 6n^2 - 6n\cot\alpha + 6n\cot\delta$$

$$D_2 = A\left(\cot\beta + \cot^3\delta + 3\cot\alpha\cot^2\delta - 3\cot\alpha\cot\beta\cot\delta - 6n\cot\alpha\cot\delta\right)$$

In this report a linear variation with depth is assumed regarding the shear strength of normally consolidated soils as follows:

$$c = a_0 \cdot z, \quad c_0 = 0 \quad \text{.......... (5.3)}$$

$$c = \sigma\tan\phi = \gamma z\tan\phi \quad \text{.......... (5.4)}$$

Then,

$$a_0 = \gamma\tan\phi \quad \text{.......... (5.5)}$$

$$Fs = \frac{a_0}{\gamma}N_1 = \frac{\gamma\tan\phi}{\gamma}N_1 = \tan\phi N_1 \quad \text{.......... (5.6)}$$

Thus, the safety factor depends on the angle of shear strength and stability number, N_1 representing the configuration of the slope and failure surface. The minimum values of the stability number are determined by carrying out a parametric study in terms of α, δ and n to find the most critical failure surface as given in Figure 5-30. The variation of minimum N_1 can be expressed as a function of β (slope angle) and A (earthquake acceleration). It becomes possible at this stage to calculate the minimum safety factor Fs using Figure 5-30 if ϕ (shear strength angle) can be determined or estimated.

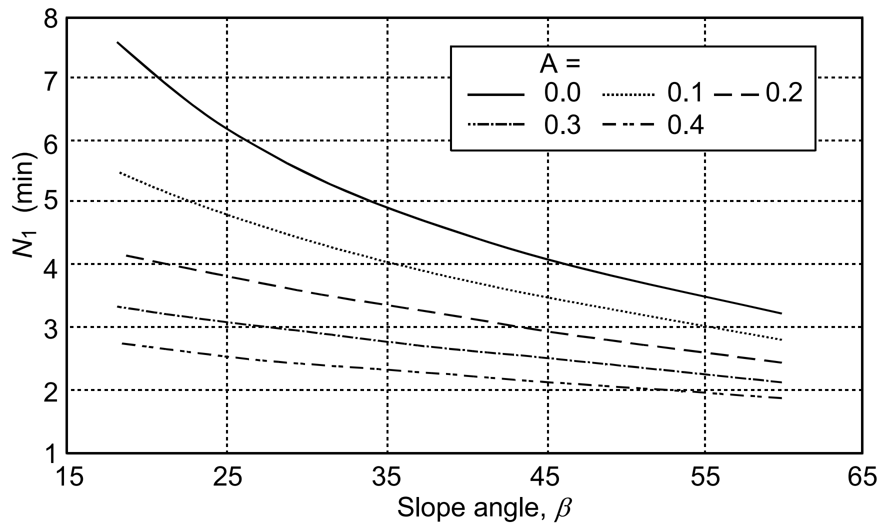


Figure 5-30 Variation of N_1 (min) (Ansal and Siyahi, 1994)

Considering slope hazard, two points of view are necessary. One is the trigger factor, the seismic ground motion. The other is inherent factors such as soil resistance or slope dip.

Of the above two methods, both can be considered from two viewpoints. The former is PGA (see Section 5-3-3), which is applied for the trigger factor. The latter is the factor expressed as c, ϕ and slope angle.

Regarding these factors, the procedure to be considered is described in the following chapter.

5-5-3 Preconditions for the Analysis

(1) Geo-technical properties

As outlined in Section 3-3-2, c and ϕ of each layer are defined in Table 5-8. Using these data, the critical acceleration against the slope-inclination is calculated using Wilson's method and Ansal and Siyahi's method.

The results are shown in Figure 5-31. In this figure, 'mi' and 'p2l' were calculated based on Wilson's method. In this case, acceleration is 'Critical acceleration' and the thickness of the sliding layer should be known. In this Study, this parameter was estimated to be 2m thick (refer to Photo 5-5 and Photo 5-6). The other types of soil were calculated by Ansal and Siyahi's method, with acceleration being 'the acceleration in the case of Fs=1'.

Table 5-8 c and ϕ of geotechnical properties (refer to Section 3-3-2)

Symbol	c (kgf/cm^2)	ϕ (degree)	Symbol	c (kgf/cm^2)	ϕ (degree)
ap	0.6	34	e	0.5	27
a3	0.9	27	a2	0.8	22
q	0.6	25	qt	0.7	28
p2c	0.7	23	p2l	0.4	27
p1	0.7	22	mi	0.4	28

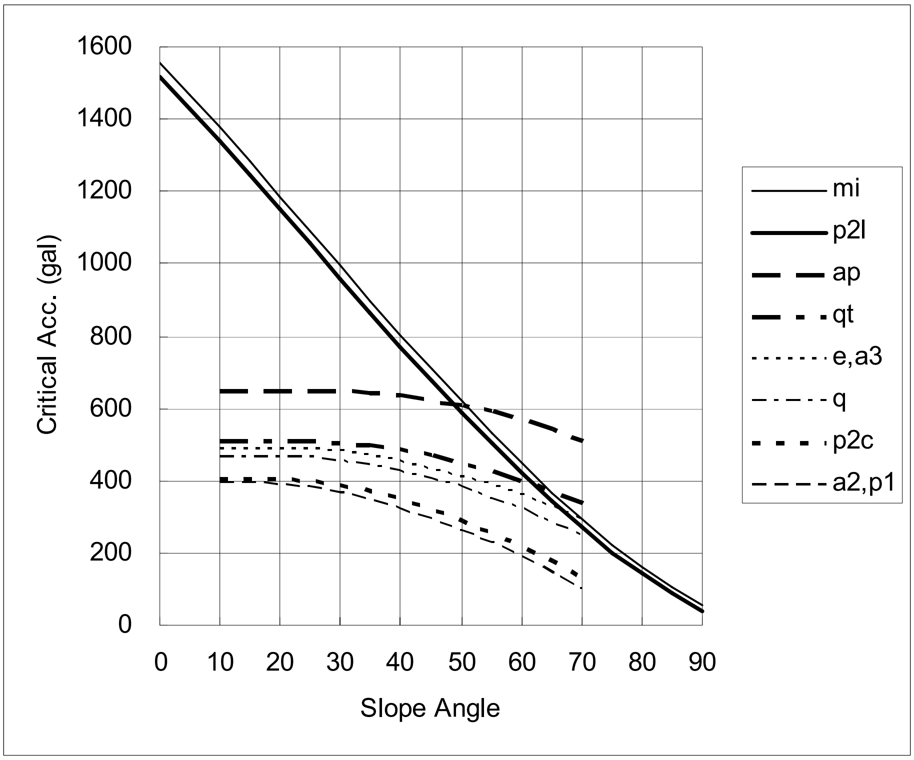


Figure 5-31 Relationship between Slope Angle and Critical Acceleration

(2) Distribution of slope angles

The slope angle was calculated for 5m intervals based on the DEM data, which was produced by INCT. The distribution of slope gradient is shown in Figure 5-32. This figure shows that many steep slopes exist in BOUZAREAH and RAIS HAMIDOU and additionally along the valley in EL MADANIA and BIR MOURAD RAIS. This figure also shows several errors, namely false slopes based on the DEM data errors. One example is two big false slopes; one of them runs north to south from the west end of EL MADANIA to DJASR KASANTINA and another runs east to west from SIDI M'HAMED to DELY BRAHIM. Other examples are the many small slopes in OUED SMAR and DER EL BEIDA. The shape of these small slopes reflects the shape of buildings or highways.

After precise exploration of the DEM data and calculated slope distribution, the areaenclosed by the black line in Figure 5-32 was extracted as the "Usable Area" for the slope analysis. Outside of the "Usable Area", the elevation data based on the 1/10,000 topographical map was used instead of INCT DEM. The distribution of slope angle based on the 1/10,000 topographical map is shown in Figure 5-33.

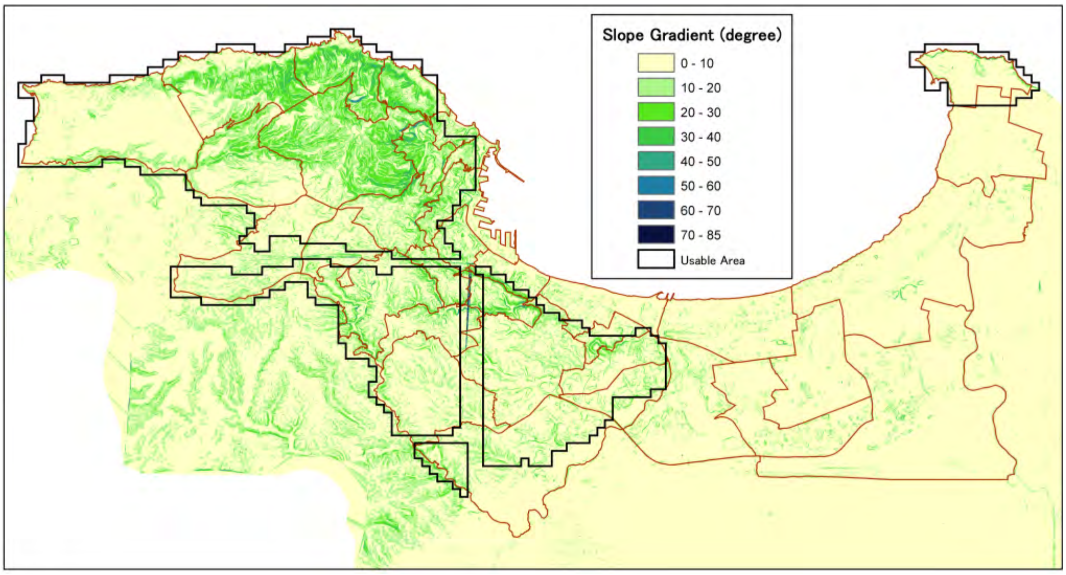


Figure 5-32 Slope Gradient Distribution Calculated from INCT DEM

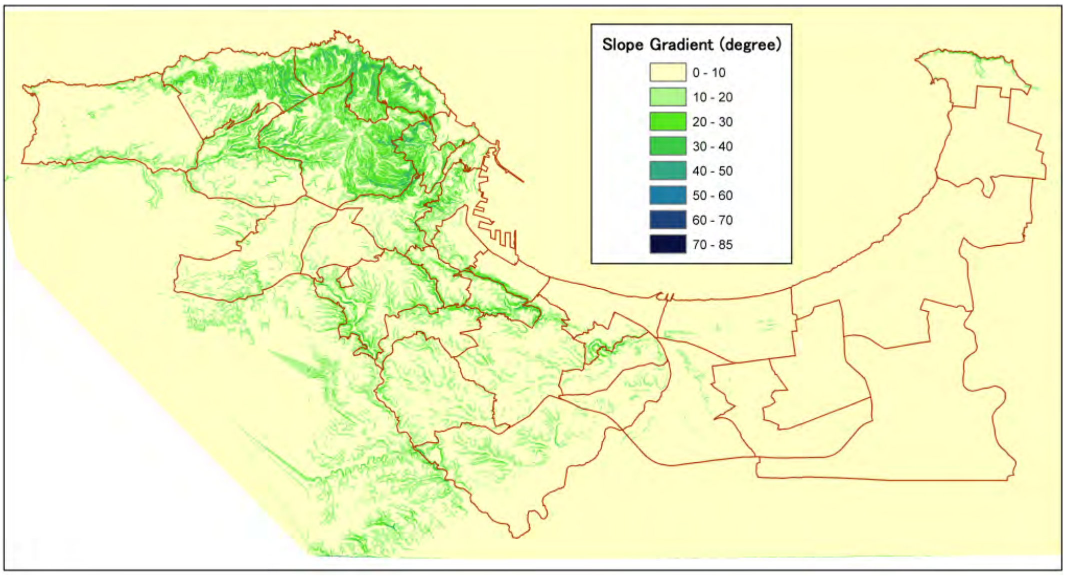


Figure 5-33 Slope Gradient Distribution Calculated from 1/10,000 Topographic Map

There are 2,500 DEM data points in one 250 m grid section, therefore 2,500 slope angles are calculated in each grid section. The frequency distribution of 5 m pitch slope angle in each 250 m grid section was analysed. Figure 5-34 shows the example of grids in BOUZAREAH.

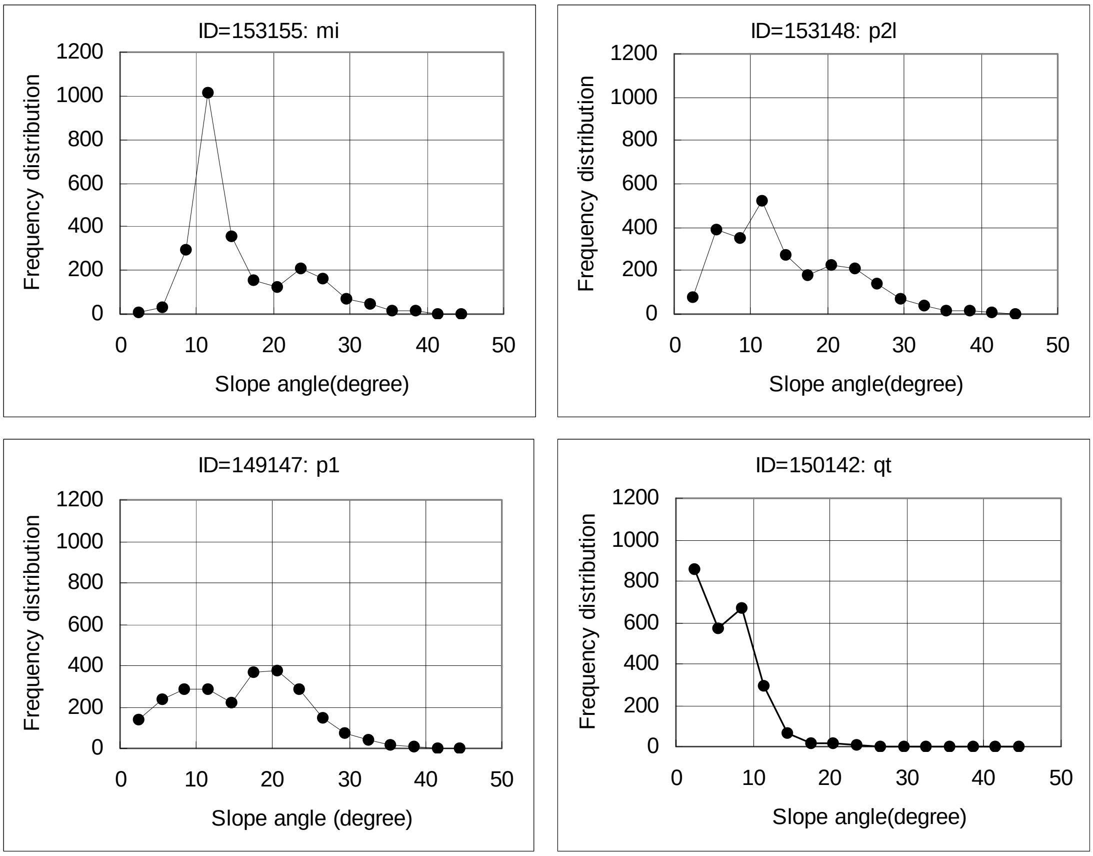


Figure 5-34　Example of the Frequency Distribution of Slope Angle in the Grid

(3)　Correction of the slope angle

In using the DEM data for slope analysis, the limitation of accuracy based on the sampling interval should be considered.　For example, the slope angle of a) (90 degrees) and b) (45 degrees) in Figure 5-35 are not the same; however if the interval of the DEM is larger than 3 m, the elevation in the DEM may be identical for a) and b).　The difference between actual slope angle and calculated slope angle from the DEM increases as it becomes steeper.　Slope correction was carried out based on the properties of 5 m interval DEM data.

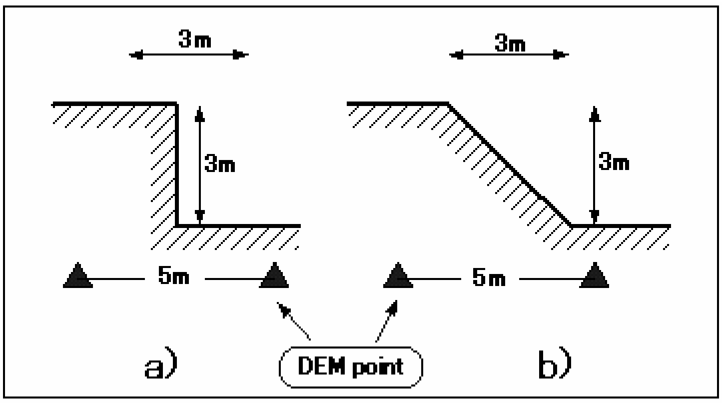


Figure 5-35　Actual Slope and DEM Data

Table 5-9 Considering the Slope Angle Correction

Height of Slope (m)	Width of Slope (m)		Slope Angle (degrees)		Remarks
	Actual Condition	in 5 m DEM	Actual Condition	in 5 m DEM	
3	0	5	90.0	31.0	a) in Figure 5-35
	1		71.6		
	2		56.3		
	3		45.0		b) in Figure 5-35
	4		36.9		
	5		31.0		
	6	10	26.6	16.7	
	7		23.2		

Table 5-9 shows an example of slope angle correction. If the height of the slope is 3 m and the width is 3 m, the actual slope angle is 45.0 degrees; however the slope angle calculated using a DEM with 5m interval shows 31.0 degrees because the minimum width of the DEM is 5 m. The numerical parameter study was conducted for many slopes with various heights and widths and the relationship between actual slope angle and slope angle based on the DEM was studied. Based on this study, a correction formula was developed as shown in Figure 5-36.

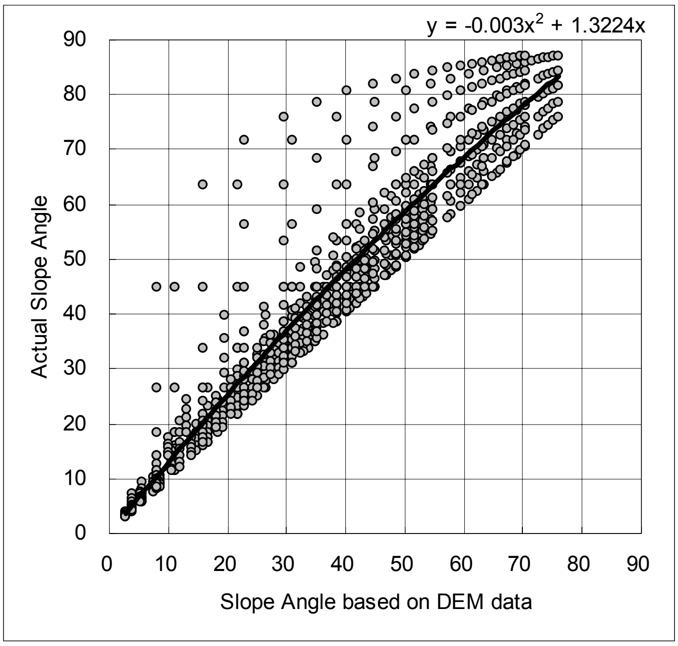


Figure 5-36 Correction Formula for Slope Angle

The correction formula to estimate actual slope based on a 5 m DEM is as follows.

$$Sa = -0.003Sd^2 + 1.3224Sd \quad \text{.......} \quad (5.7)$$

Sa : Actual Slope Angle (degree)

Sd : Slope Angle based on 5m DEM data

In other words, a 40 degree DEM slope angle implies with a high probability that the actual angle is 48 degrees (see Table 5-10). Therefore, the correction formula (5.7) was applied to estimate the actual slope angle from the DEM data analysis.

Table 5-10 DEM Slope Angle and Corrected DEM Slope Angle

DEM Slope Angle (degrees)	Corrected Slope Angle (degrees)	DEM Slope Angle (degrees)	Corrected Slope Angle (degrees)
10	13	50	59
20	25	60	69
30	37	70	78
40	48		

The PGA value at each grid is available from the ground motion study. Comparing the PGA value for each scenario earthquake and 'Critical acceleration', the stable ($Fs \geq 1$) or unstable ($Fs < 1$) was judged at each 5m DEM data point. The slope failure potential of each 250 m grid section was evaluated based on the ratio of unstable DEM data points in each grid section. Figure 5-37 shows the flowchart of this process.

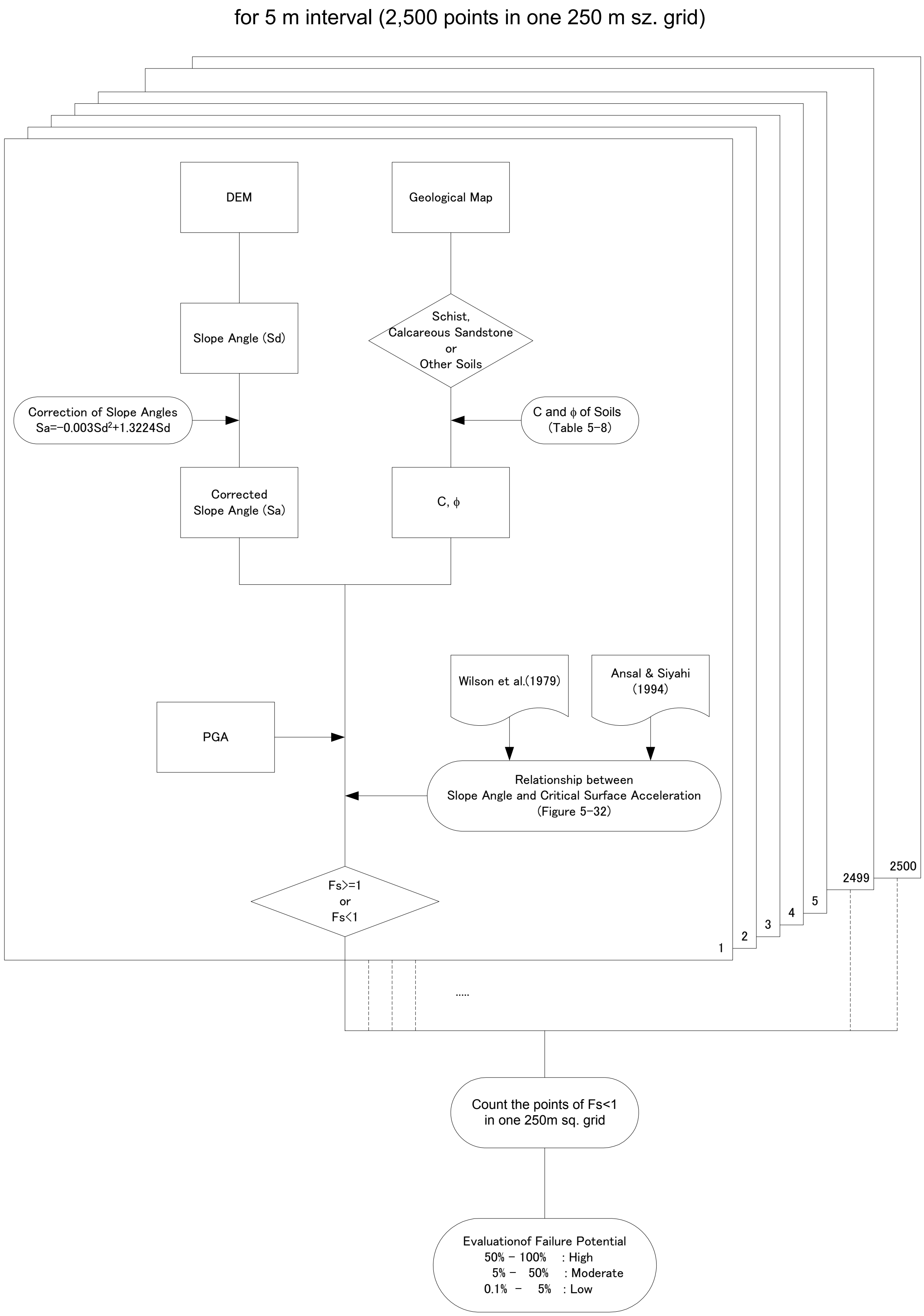


Figure 5-37 Flowchart of Slope Stability Analysis

CHAPTER 6

DAMAGE ESTIMATION

Chapter 6. Damage Estimation

6-1 Damage to Buildings

The European Macroseismic Scale, EMS (formerly MSK) was applied for building damage estimation. Damage to buildings will be estimated based on the number of buildings, vulnerability of each structural typology, and intensity of ground motion in each 250 meter square grid cell. In this Study, the 1998 census data, digital map data and the inventory survey by URBANIS under the JST were adopted for the building damage estimation.

6-1-1 Building Categories

According to the building inventory survey, a study of the Algerian Seismic Code, and an investigation of damage ratios of past earthquakes in the Study Area, JST and CGS identified 8 categories for buildings. Categories are decided by type of structure, and year constructed and/or seismic design code followed, as shown in Table 6-1.

Building categories shown in Chapter 4-1-1, Building Inventory Survey were reduced from 11 to 8-categories, considering 1) from a study of earthquake damage there was no clear correlation between the number of stories and damage ratio. 2) An RC wall and frame structure was evaluated to be the same as an RC wall structure. 3) Miscellaneous type such as a concrete block structures was included in 'Stone and Brick Masonry'.

The categories of RC frame built to the Moderate-Code (RPA99) and RC frame built to the High-Code (RPA99 ver. 2003) were included to approximate the improvement in seismic capacity of buildings designed to these seismic design codes.

The ratio of each type of structure in each Commune is shown in Table 6-2.

For the number of buildings in each Commune, refer to Table 4-1, Number of Buildings and Dwelling Units in Communes, of Chapter 4.

Table 6-1 Building Categories for Damage Estimation

Type	Type of Structure	Structural Category	Number of Stories	(Construction) Year or Design Code
1	Masonry	Brick Masonry at CASBAH	all	all
2		Stone and Brick Masonry	all	all
3	Reinforced Concrete	RC Frame Pre-code	all	till 1980 for public and till 2003 for majority of private
4		RC Frame Low-code	all	1981 - 99 for public or designed by RPA81 (83), 88
5		RC Frame Moderate-code	all	2000 - 02 for public and private designed by RPA99
6		RC Frame High-code	all	2003 and after for public and private, designed by RPA2003
7		RC Shear Wall and Mixed	all	all
8	Steel	Steel	all	all

Table 6-2 Ratio of Structural Type of Buildings in each Commune

Type of Structure	ID	1601	1602	1603	1604	1605	1606	1607	1608	1609	1610	1611	1612
	COMMUNE	ALGER CENTER	SIDI M HAMED	EL MADANIA	HAMMA EL ANNASSER	BAB EL OUED	BOLOGHINE	CASBAH	OUED KORICHE	BIR MOURAD RAIS	EL BIAR	BOUZAREAH	BIRKHADEM
Old Brick Masonry at Casbah	%	0.0	0.0	0.0	0.0	0.0	0.0	35.7	0.0	0.0	0.0	0.0	0.0
Stone and Brick Masonry	%	77.4	66.0	72.4	12.5	75.5	37.5	64.3	46.7	25.0	33.3	15.8	31.3
RC Frame Pre-code	%	20.8	30.0	13.8	75.0	18.4	50.0	0.0	53.3	41.7	56.7	68.4	65.6
RC Frame Low-code	%	0.0	4.0	3.4	12.5	4.1	8.3	0.0	0.0	4.2	6.7	2.6	0.0
Steel	%	0.0	0.0	0.0	0.0	2.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0
RC Wall	%	0.0	0.0	10.3	0.0	0.0	0.0	0.0	0.0	25.0	3.3	10.5	3.1
RC Frame Medium-code	%	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	2.6	0.0
RC Frame High-code	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Type of Structure	ID	1613	1615	1616	1617	1618	1619	1620	1621	1622	1623	1624	1625
	COMMUNE	EL HARRACH	OUED SMAR	BOUROUBA	HUSSEIN DEY	KOUBA	BACH DJARAH	DAR EL BEIDA	BAB EZZOUAR	BEN AKNOUN	DELY BRAHIM	HAMMAMET	RAIS HAMIDOU
Old Brick Masonry at Casbah	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stone and Brick Masonry	%	55.6	0.0	25.6	46.4	25.0	18.0	0.0	3.9	9.1	0.0	18.2	41.7
RC Frame Pre-code	%	37.0	91.7	62.8	39.3	35.7	48.0	44.0	21.6	54.5	82.4	81.8	41.7
RC Frame Low-code	%	0.0	8.3	4.7	3.6	10.7	12.0	32.0	15.7	0.0	5.9	0.0	0.0
Steel	%	0.0	0.0	0.0	3.6	1.8	0.0	8.0	0.0	0.0	0.0	0.0	0.0
RC Wall	%	3.7	0.0	2.3	3.6	26.8	22.0	16.0	49.0	36.4	0.0	0.0	16.7
RC Frame Medium-code	%	3.7	0.0	4.7	0.0	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0
RC Frame High-code	%	0.0	0.0	0.0	3.6	0.0	0.0	0.0	2.0	0.0	11.8	0.0	0.0

Type of Structure	ID	1626	1627	1628	1629	1630	1631	1632	1639	1640	1644	Total
	COMMUNE	DJASR KACENTINA	BELOUIDAD	HYDRA	MOHAMMADIA	BORDJ EL KIFFAN	EL MAGHARIA	BENI MESSOUS	BORDJ EL BAHRI	EL MARSA	AIN BENIAN	
Old Brick Masonry at Casbah	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Stone and Brick Masonry	%	10.9	84.8	0.0	13.0	15.3	11.8	10.0	13.3	20.0	24.1	33.6
RC Frame Pre-code	%	37.0	6.1	75.0	34.8	18.6	58.8	50.0	66.7	80.0	44.8	40.6
RC Frame Low-code	%	10.9	0.0	0.0	30.4	49.2	5.9	30.0	13.3	0.0	24.1	10.0
Steel	%	2.2	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.9
RC Wall	%	39.1	9.1	20.0	21.7	3.4	23.5	10.0	6.7	0.0	6.9	11.9
RC Frame Medium-code	%	0.0	0.0	5.0	0.0	10.2	0.0	0.0	0.0	0.0	0.0	1.7
RC Frame High-code	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4

6-1-2 Building Damage from the 1980 El Asnam and 2003 Boumerdes Earthquakes

(1) 1980 El Asnam Earthquake

CTC (Controle Technique de la Construction) surveyed the damage to approximately 10,000 buildings using a “Damage Evaluation Form”. They classified damages by 5 grades, and the results were immediately shown to citizens in the building with damage levels in 3-colours as follows:

- Green: possible to use
- Red: impossible to use, and
- Orange: after detailed check will be judged whether possible to use or not.

According to the investigation report, “1980 Algeria Earthquake”, by the Architectural Institute of Japan, over 80 % of surveyed buildings were damaged. It reported that more than 40 % of the buildings were heavily damaged or had collapsed, 20 % of the buildings were slightly damaged, and the remaining 40 % of buildings required detailed investigation to determine their safety. Over 90 % of stone or brick masonry structures suffered severe damage.

Many reinforced concrete buildings were heavily damaged and characteristics were summarized as follows;

a) Damage caused by an imbalance of wall in plan or in elevation, like pilotis
b) Shear failure of columns with standing or hanging walls
c) Failure of short columns with column sizes of 25 cm square for crawl space for 3 to 4 storey houses
d) Damage caused by the lack of space for expansion joints

However, most reinforced concrete buildings with reinforced concrete walls were only slightly damaged. There were a few steel and wooden structures with very little seismic damage. The Classification of Damage to Masonry and RC Buildings by EMS-98 is shown in Chapter 4-1-2.

(2) 2003 Boumerdes Earthquake

CGS (National Earthquake Engineering Research Center) and CTC performed a damage survey of over 400,000 dwelling units in Algiers, and over 16,000 dwelling units in Boumerdes, for the 2003 Boumerdes Earthquake. The survey will be analyzed in detail by CGS. JST obtained some study data of building damage in some communes from CGS as an initial report and a summary of damage data by dwelling units from CTC Chlef.

The summary of damage by dwelling units for the communes in the study area due to the 2003 Boumerdes Earthquake is shown in Chapter 4-1-2.

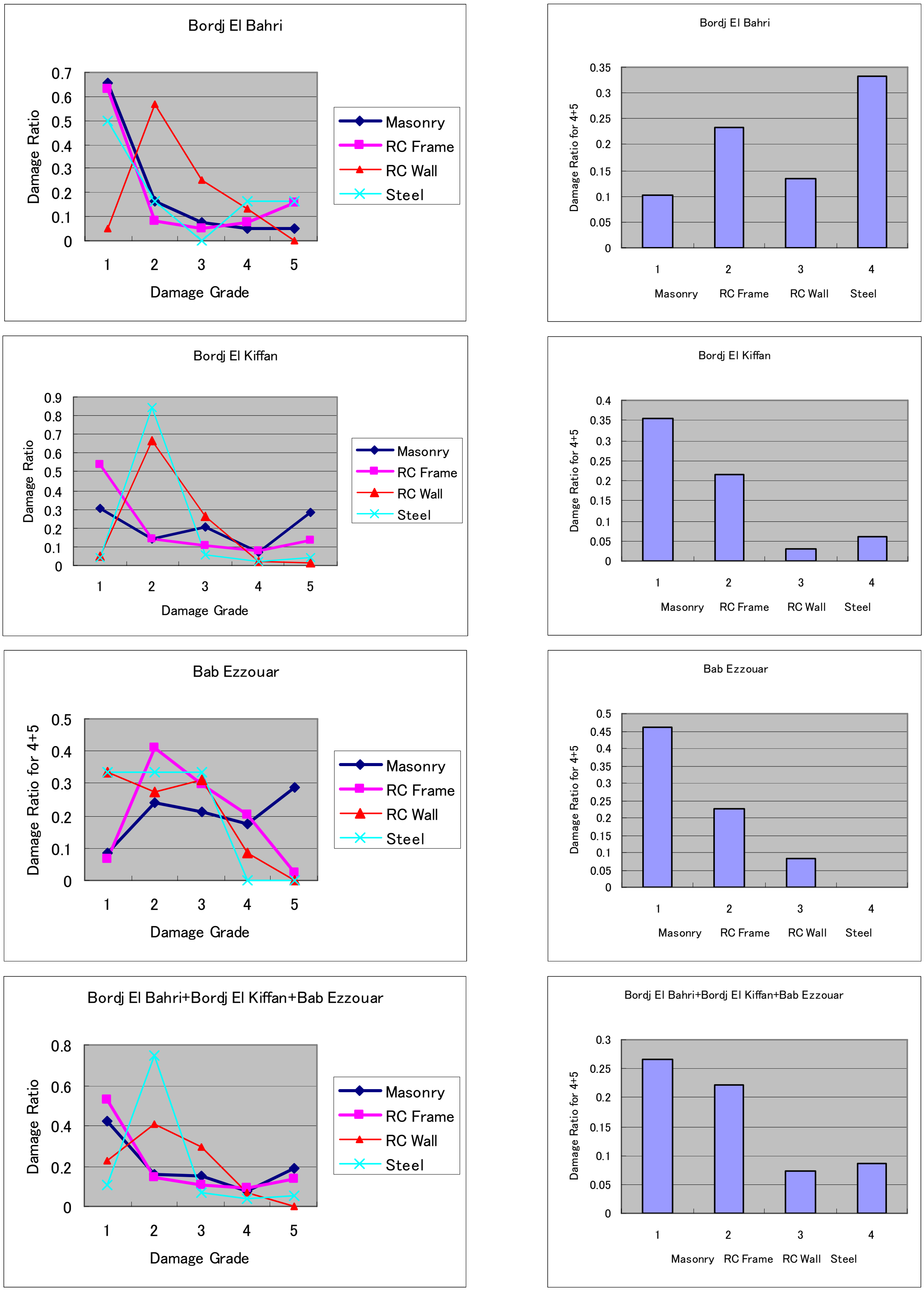
In a damage survey of buildings done by CGS after the 2003 Boumerdes earthquake, data of the following four communes on the east side of Wilaya Algiers in the Study Area were provided:

BAB EZZOUAR, BORDJ EL KIFFAN, BORDJ EL BAHRI and EL MARSA

Among them, data of EL MARSA was not used because of the small quantity of survey data.

Buildings of limited area and block were entirely surveyed, but not the all buildings in each commune. The main structural types were masonry, reinforced concrete moment frame, reinforced concrete wall structure and steel structures. The ratio of each damage grade from 1 to 5 and the ratio of damage grades 4 & 5 for each structural type are shown in Figure 6-1. For the Classification of damage grade by EMS-98, refer to Chapter 4-1-2.

The damage function was discussed and estimated with CGS mainly based on a study of the damage investigation for the 2003 Boumerdes Earthquakes. A building damage estimation was performed for each scenario earthquake based on the damage function.



(original source; CGS)

Figure 6-1 Results of Damage Survey

6-1-3 Building Damage Function

(1) General

A flow chart for preparation of a damage function (or vulnerability function) for this study is shown in Figure 6-2.

Seismic intensity in the study area during the 2003 Boumerdes earthquake was estimated in this Study, while the building damage data in the study area was limited as shown below. Seismic capacity of each structural type was estimated with suppositions and combined with the surveyed damage data, to supplement the lack of damage data. Then the damage function was obtained.

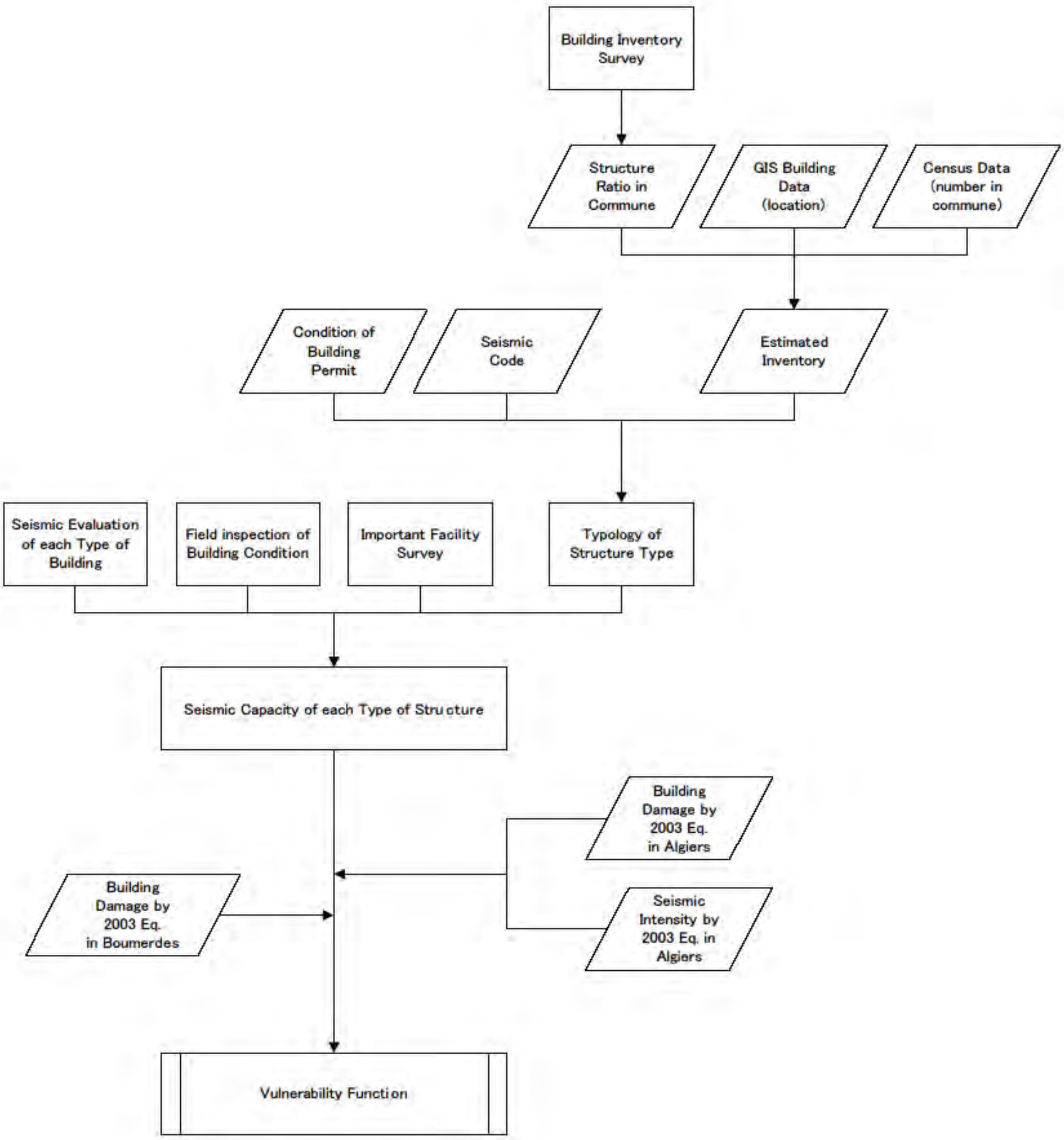


Figure 6-2 Flow Chart for Damage Function (Vulnerability Function)

The damage survey results for four structural types as caused by the 2003 Boumerdes earthquake for the following three communes in the study area were provided by CGS as shown in the Section 1-2.

BAB EZZOUAR, BORDJ EL KIFFAN and BORDJ EL BAHRI

These communes are located on the east side of Wilaya Algiers, estimated EMS (formerly MSK) seismic intensity during the 2003 Boumerdes earthquake was around 8, and there was no clear difference among the three communes. As a result, it was not possible to produce a damage function for buildings from the damage survey data as shown in Figure 6-3.

It has been proposed to introduce the idea of a distribution of seismic index of structure, Is, for each structural type and to combine that with the surveyed damage ratio in order to develop a damage curve. This is a new methodology for determining a building damage function. This methodology of damage curves is shown as follows, through a damage curve for a Pre-code (non-engineered) RC frame structure.

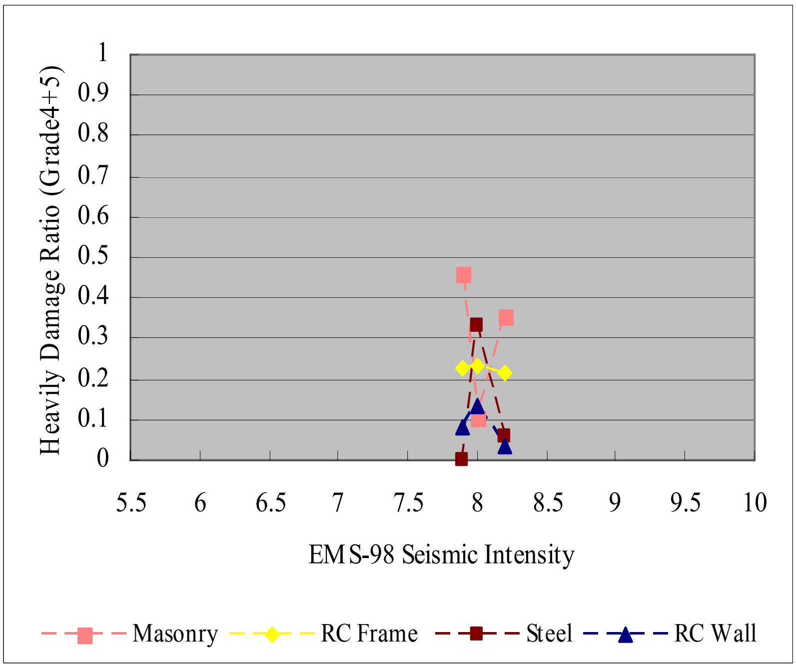


Figure 6-3 Surveyed Damage Ratio for Four Structural Types and Estimated Seismic Intensity for Three Communes in the Study Area caused by the 2003 Boumerdes Earthquake

(2) Damage Ratio for the Damage Function

The heavily damage ratio, which is defined as grade 4 & grade 5 of EMS-98, has been used for the vertical axis of the 'Damage Function'. Grade 4 is very heavy damage (heavy structural damage, very heavy non-structural damage). Buildings with grade 4 damage are unusable for evacuation purposes after an earthquake, and retrofit cost becomes very high or similar to that of new construction. Grade 5 is destruction (very heavy structural damage). Refer to Chapter 4-1-2 for damage grades. It is well known that there is a correlation between heavy damage ratio and human causalities.

(3) Seismic Intensity and Surveyed Damage Ratio

EMS seismic intensity related to PGA has been used for the horizontal axis of the 'Damage Function' (refer to Chapter 5 for the Estimation of Ground Motion).

Estimated seismic intensity at each grid sector of a commune caused by the 2003 Boumerdes earthquake varied widely. For example, values from a minimum of 7.4 to a maximum of 9.0 were estimated for the 250 m grid sector of Commune Bordj El Kiffan (1630). The ratio of surveyed buildings to existing buildings (in the building inventory survey) was from 14 % to 26 % and the location of surveyed buildings has not been summarized. Since the number of surveyed buildings was limited and those locations were not clear, it will be evaluated that the surveyed damage ratio of buildings, shown in the Section 1-2, will be the ratio against upper range of estimated seismic intensity and will be bigger than the actual ratio against estimated average seismic intensity as a commune.

Table 6-3 Estimated Seismic Intensity caused by the Boumerdes Earthquake

Name of Commune	Estimated Seismic Intensity	Ratio of Buildings Surveyed
BAB EZZOUAR	average 7.9 (min.7.4~max.8.5)	14 %
BORDJ EL KIFFAN	average 8.2 (min.7.4~max.9.0)	22 %
BORDJ EL BAHRI	average 8.0 (min.7.8~max.8.8)	26 %

Engineering judgment indicates that reduced values of the surveyed damage ratio should be used at an average seismic intensity of 8.0, and this was combined with a distribution of the seismic index structure, Is, of each structural type.

(4) A Methodology Incorporating the Seismic Index of Structure, Is,

The damage function for Pre-code (non-engineered) RC moment frame structures was estimated as follows;

1) The Seismic Index of Structure, Is, for Pre-code (non-engineered) RC Frame Structures

A seismic evaluation was executed for a typical 'Pre-code' 5 storey apartment house, called a non-engineered building. The result was shown in Figure 6-4. Detailed results are shown in the Appendix of Chapter 9-1-2.

The Seismic Index of Structure, Is, was shown for various concrete strengths. Concrete strength of 25 N/mm^2 was required by the standard, but concrete strength of 14 to 17 N/mm^2 was found in core samples of heavily damaged buildings after the 2003 Boumerdes earthquake, according to the CGS's preliminary report. From this figure, Is, 0.28 which was the value for concrete strengths satisfying the standard, was estimated as a typical value and a peak value of a distribution of 'Pre-code' RC frame structures as shown.

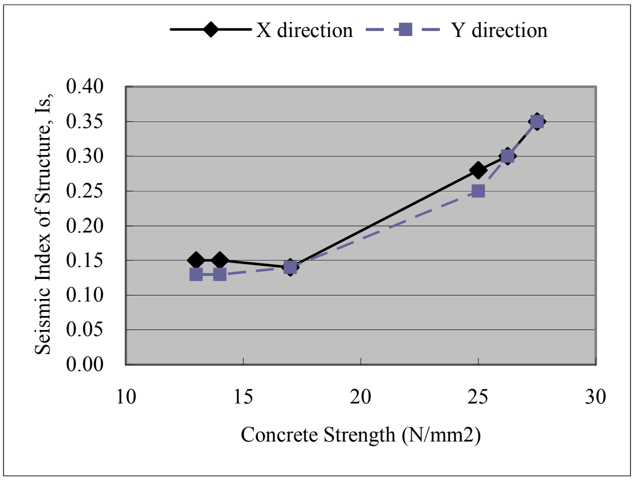


Figure 6-4 Seismic Index of Structure, Is, and Concrete Strength

2) Distribution of Seismic Index of Structure, Is, and Earthquake Damage

The distribution of Seismic Index of Structure, Is, of reinforced concrete buildings in Shizuoka prefecture in Japan is shown in ① of Figure 6-5 (Reference 1). The distribution of Is for moderate and heavily damaged buildings following two earthquakes is shown in ③ of the same Figure;

- 1968 Tokachi Off Earthquake, M7.9 Intensity JMA 5+ (to 6-)
- 1978 Miyagi Off Earthquake, M7.4 Intensity JMA 5+ (to 6-)

As shown in Figure 6-5, the following items are observed;

(A) Distribution of the Seismic Index of Structure, Is, is approximated by a normal logarithmic distribution. (Note; as shown later, the distribution of the Seismic Index of Structure, Is, was simplified and approximated by a modified normal distribution)

(B) Buildings with lower Is values are easily damaged and buildings with higher Is values are more difficult to damage, subject to seismic intensity.

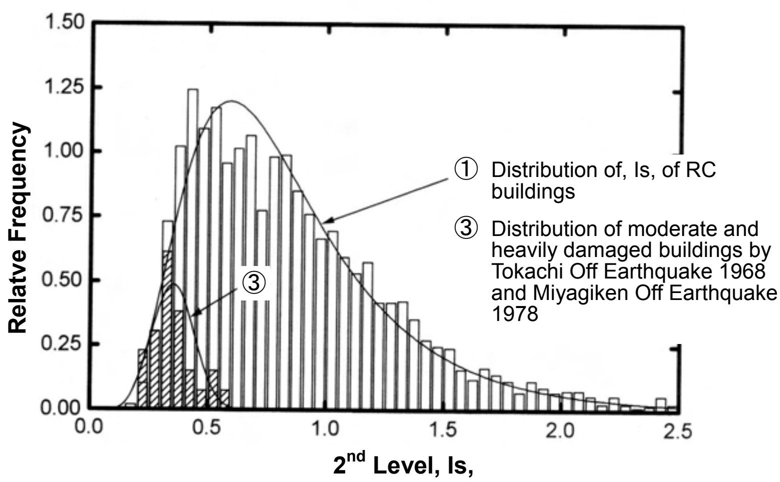


Figure 6-5 Distribution of Seismic Index of Structure, Is, and Earthquake Damage

3) Distribution of Seismic Index of Structure, Is, for Pre-code (Non-engineered) Reinforced Concrete Frame Buildings

Normal distribution with a peak Is of 0.28 and deviation of 0.20 is assumed. The distribution curve is modified with linear lines for both sides so that area 1 and area 2 are the same. The area of the modified distribution is also 1.0 (see Appendix 1, 'Deviation and Damage Function').

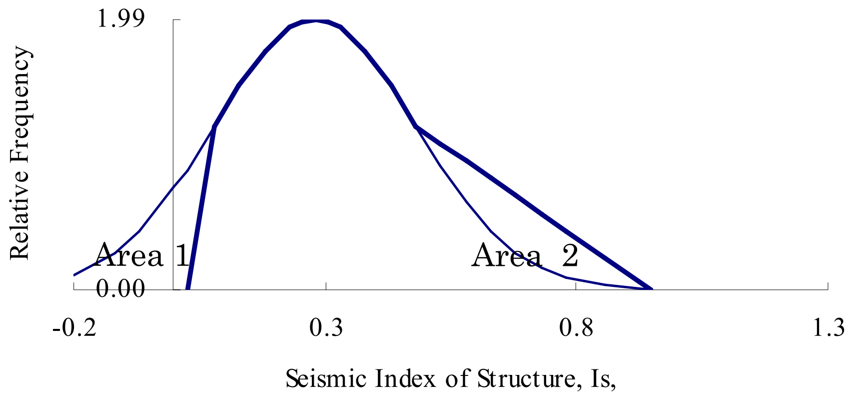


Figure 6-6 Distribution of Seismic Index of Structure, Is, for Pre-code RC Frame Structures

4) Damage Ratio of Buildings as determined by Survey

The variation in the damage ratios for the individual grid sectors was great compared with the average damage ratio of the Commune taken as a whole. In this case, as stated in the previous section, engineering judgment indicated that approximately 2/3 of the results produced by the survey should be used to establish the EMS (formerly MSK) intensity value of 8 to represent the average of the three communes.

The area under the curve for the values of Is equal to and below 0.165 was found to represent the heavily damaged ratio, 0.137, which is an average of the 'Pre-code (0.157)' and 'Low-code (0.117)' values, and this was equal to 62% of the surveyed damage ratio, as shown in Table 6-4. This assumed that the number of 'Pre-code' and 'Low-code' buildings was similar to those found in the building inventory survey. A simplified vertical Is value line was used as a boundary line for the estimation.

It is noted that the Is boundary value of 0.165 covers the range of values 0.13 to 0.15, which were the values of heavily damaged buildings as shown in Section 1-3 (3). This Is value of 0.165 was also applied for other structural types for the estimation of the damage ratio produced by an event of seismic intensity 8.

Table 6-4 Estimated Damage Ratio for Pre-code RC Frame Structures and Low-code RC Frame Structures and Surveyed Damage Ratio

Type of Structure	Area equal and below 0.165 of Distribution of, Is,:(b)	Damage Ratio of 'RC Frame' structures caused by the Boumerdes Earthquake:(a)	(b)/(a)
RC Frame Pre-Code	0.157	0.222 (max.0.234, min.0.206)	0.62
RC Frame Low-Code	0.117		

Note; It was supposed that the surveyed category 'RC Frame' consists of Pre-code RC Frames and Low-code RC Frames and that these were similar in quantity in the surveyed three communes, based on Table 6-2 "Ratio of Structural Types of Buildings in each Commune".

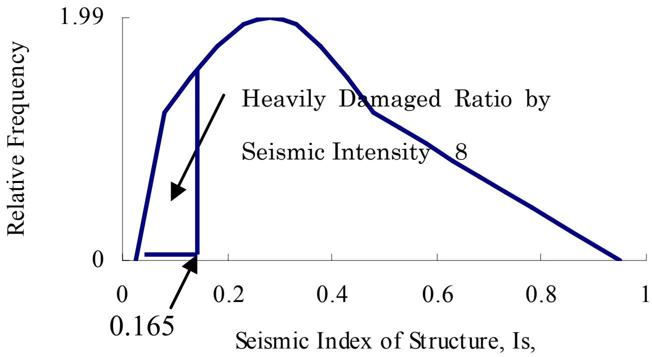


Figure 6-7 Heavily Damaged Ratio shown by the Area of Distribution of Is

5) PGA and Seismic Intensity in the MSK Scale

The area under the curve for Is values equal to and below 0.165 (Is boundary value is 0.165) is 0.157 which is the damage ratio produced by EMS intensity 8 for Pre-code (Non-engineered) Reinforced Concrete Frame Buildings.

For other seismic intensities, seismic motion intensity 7 is 0.48 times of that of intensity 8. Seismic motion of intensity 9 is 2.1 times of that of intensity 8. Intensity 10 is 4.4 times of that of intensity 8 as shown in Figure 5-24, "Empirical Relation between PGA and Seismic Intensity in MSK (currently EMS) Scale" in Chapter 5.

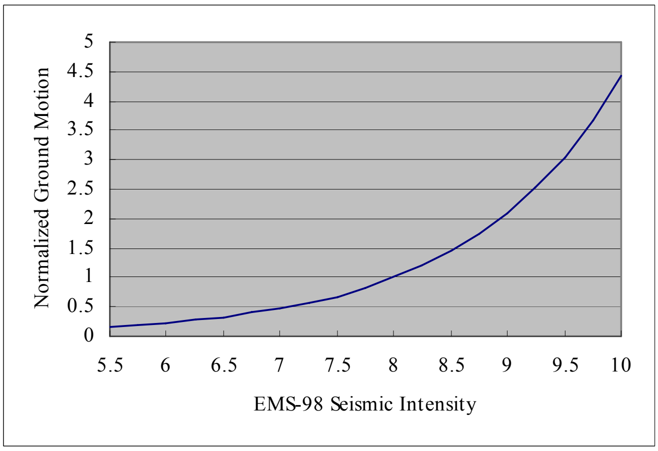


Figure 6-8 Normalized Ground Motion and Seismic Intensity (Normalized for Seismic Intensity 8)

6) Production of Damage Function

A similar calculation was done for the area of the distribution of Is and normalized seismic intensity and thus, a 'Damage Function' for Pre-Code RC Frame structures was obtained.

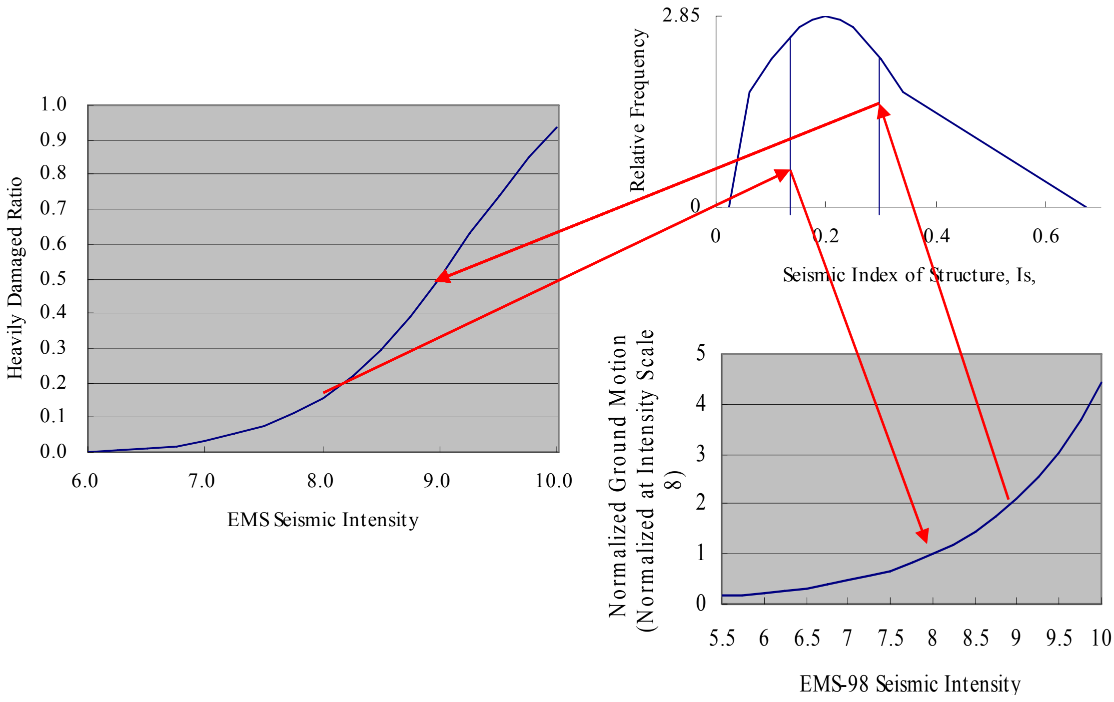


Figure 6-9 Seismic Index of Structure, Seismic Intensity and Heavily Damaged Ratio

7) Structural Types other than Pre-code RC Frame

(A) Stone and Brick Masonry, Steel and RC Wall Structures

The surveyed damage ratio of the 2003 Boumerdes earthquake was utilized. A reduced seismic intensity 8.0damage ratio was used. But the reduction ratio was not large, since the surveyed damage ratio of masonry structures at the commune Bordj El Bahri was only 10% and this was exceptionally low, because of the existence of good quality one storey masonry houses according to CGS. This was combined with the Seismic Index of Structure, Is, distribution. The distribution of these structural types was extracted based on an analogy of RC frame structures so that the damage ratio at intensity 8 is the area under the curve for Is values equal to and smaller than 0.165. Refer to Figure 6-10 "Supposed Distribution of Seismic Index of Structure, Is, for each Structural Type".

(B) Low-Code RC Frame, Moderate-Code RC Frame and High-Code RC Frame structures

Peak value of the distribution of Is was estimated from the seismic evaluation of a typical 5 storey apartment house of Low-Code RC frame. Refer to Chapter 9-1-2 (1) for more detail. Peak values of the distribution were estimated from the assumed strength and ductility for Mod-Code RC frames and High-Code RC Frames. The intensity 8 Damage ratio was estimated using an Is boundary value of 0.165.

(C) Brick Masonry in CASBAH

The estimated seismic intensity during the 2003 Boumerdes earthquake was 6.7 in CASBAH. The 6.7 intensity damage ratio for stone and brick masonry was 3.6% from the estimated 'Damage Function'. According to the 'CASBAH architectural and urban design survey office', 196 buildings were damaged by previous earthquakes, including the 2003 Boumerdes earthquake, and half of those were traditional houses and the others were colonial houses. However the grade of damage was not known. The building inventory survey indicated that of the existing buildings, 1/3 were traditional houses and 2/3 were colonial houses. This shows that the damage ratio for old brick masonry structures in CASBAH was approximately two times of that of stone and brick masonry structures in this range of seismic intensity.

As a result of the estimation from the assumed Seismic Index of Structure distribution, a damage ratio of 1.8 times that of stone and brick masonry at intensity 6.7 was estimated, and this will be the accepted value.

The damage ratio of each structural type at seismic intensity 8.0 estimated for the Damage Function, and the damage ratio as recorded in the survey after the 2003 Boumerdes Earthquake are summarized in Table 6-5.

Table 6-5 Estimated Damage Ratio of each Structural Type and Surveyed Damage Ratio

Structure Type	Damage Ratio at Intensity 8.0 by 'Damage Function' (b)	Surveyed Damage Ratio by Boumerdes Earthquake (a)	(b) / (a)
Brick Masonry at CASBAH	0.273	--	--
Stone and Brick Masonry	0.203	0.265 (max.0.462, min.0.103)	0.78
RC Frame Pre-Code	0.157	0.222 (max.0.234, min.0.206)	0.62
RC Frame Low-Code	0.117		
Steel	0.061	0.085 (max.0.333, min.0.0)	0.72
RC Wall	0.048	0.073 (max.0.133, min.0.032)	0.66
RC Frame Mod-Code	0.019	--	--
RC Frame High-Code	0.005	--	--

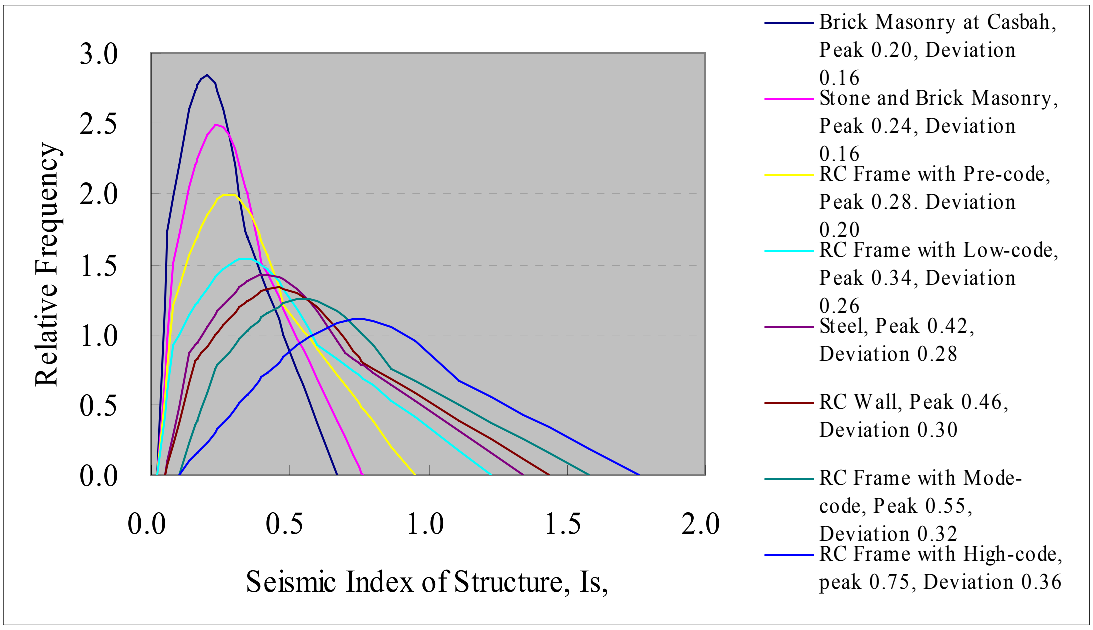


Figure 6-10 Supposed Distribution of Seismic Index of Structure, Is, for each Structural Type

(5) Damage Function

Similar estimations were done with respect to all eight structural types and the 'Damage Function' was obtained as follows;

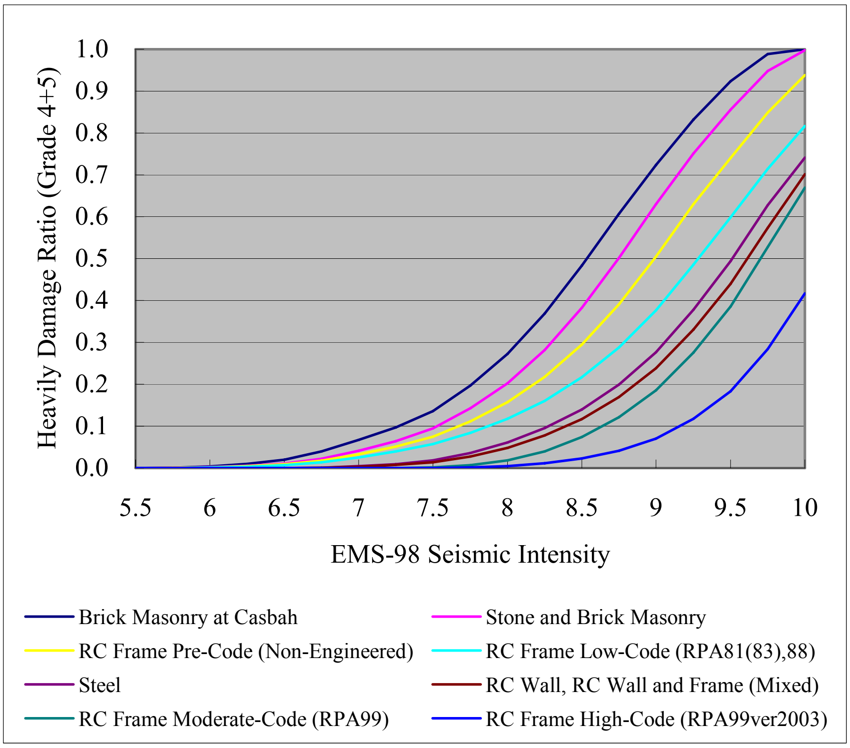


Figure 6-11 Building Damage Function

(6) Calibration

1) Calibration with Surveyed Damage Ratio within the Study Area

Damage functions were provided based on the surveyed damage ratios caused by the 2003 Boumerdes Earthquake for areas subject to seismic intensity 8. However, these damage ratios were reduced somewhat as indicated by engineering judgment as has been previously described. Analysis shows that average seismic intensity for each of the three communes was 7.9, 8.0 and 8.2 during that quake. Surveyed damage ratio and damage function for 'Stone and Brick Masonry', 'RC Frame Pre & Low-Code', and 'Steel' and 'RC Wall' are shown in Figure 6-12 for comparison.

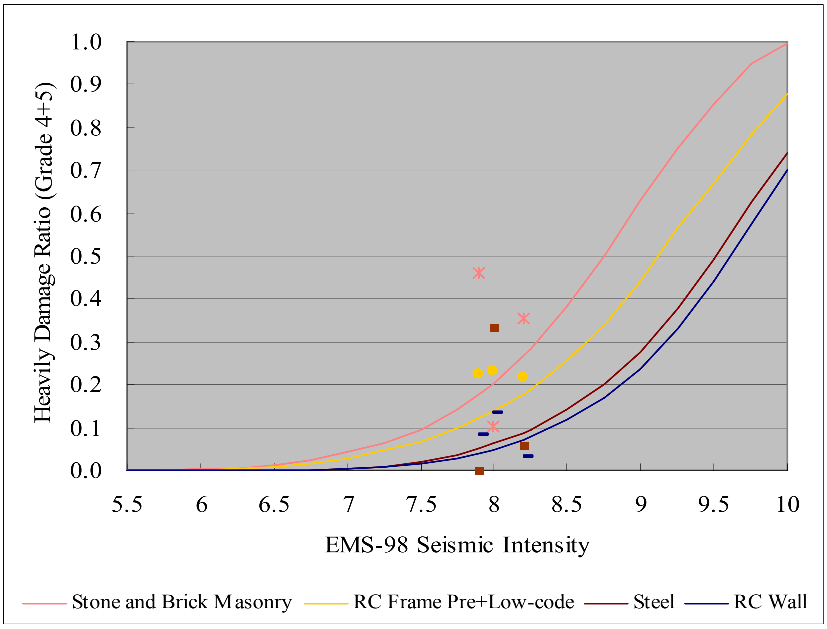


Figure 6-12 Surveyed Damage Ratio caused by the 2003 Boumerdes Earthquake and Damage Function for Four Structural Types

Surveyed damage ratio averages for four types of structures are shown in Figure 6-13. However, it should be noted that the estimated range of seismic intensity for the 250 m grid cells in the Communes varied widely (horizontal dotted line). Because of engineering judgment, the heavily damaged ratio at seismic intensity 8.0 was reduced in the range of 80 % ~ 60 % from the surveyed ratios, in another words, the surveyed heavily damaged ratios were evaluated as the ratios at seismic intensity 8.2 ~ 8.4, and not the 8.0 that was the average of actual physical intensities (arrow lines).

The damage ratio estimated utilizing the 'Damage Function' for the study area of Wilaya Algiers taken as a whole was 5.2 %. On the other hand, damage ratio reported in the survey of dwelling units (not including other types of buildings) by CTC was 7.3 %. This was 1.4 times the damage ratio for other types of buildings. This difference might be caused mainly by the difference between the survey methods for other types of buildings and dwelling units.

The average damage ratios estimated by the 'Damage Function' for grade 4 and grade 5 damage that would be caused throughout the study area of Wilaya Algiers was 28.9 % for seismic intensity EMS 8.5 and 49.4 % for EMS 9.0.

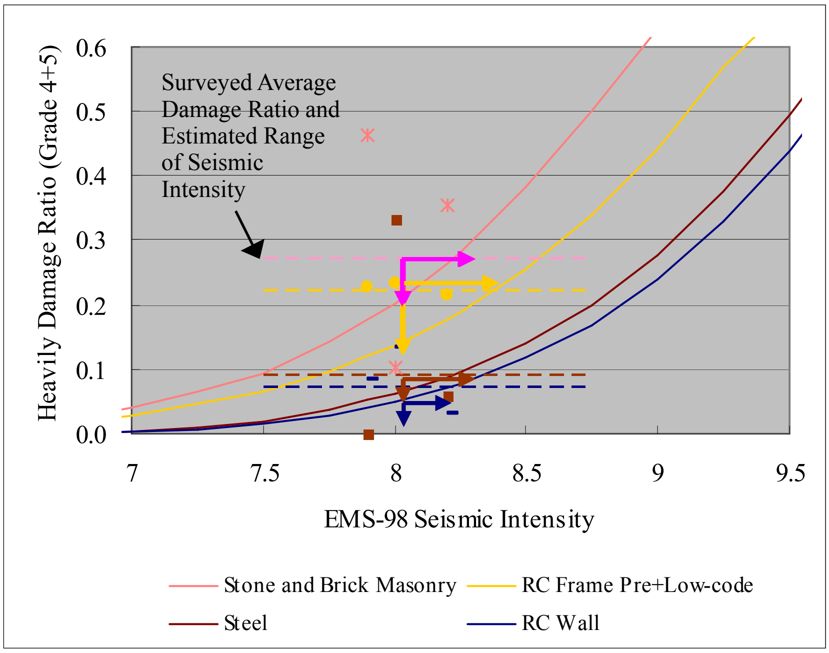


Figure 6-13 Surveyed Average Damage Ratios, Estimated Range of Seismic Intensity during the Boumerdes Earthquake and Damage Function

2) Surveyed Damage Ratio outside of the Study Area

Seismic intensity in Wilaya Boumerdes by visual evaluation in the survey after the 2003 Boumerdes Earthquake was a maximum MSK (currently EMS) 9 according to CGS. Damage data for the following communes located outside of the study area was provided by CGS, and summarized as shown in Table 6-6, for information only.

Table 6-6 Building Damage Data Outside of the Study Area for the Boumerdes Earthquake

Wilaya	Commune	Total Number of bldgs Surveyed	Number of bldgs with Grade 4 damage	Number of bldgs with Grade 5 damage	Ratio of bldgs with Grade 4 or 5 damage (%)
Algiers	ROUIBA	3369	618	258	26.0
	REGHAIA	2019	478	129	30.1
	HERAOUA	2469	400	617	41.2
Boumerdes	Boumerdes	1832	402	159	30.6
	Zemmouri	1978	312	109	21.3

[References]

The Japan Building Disaster Prevention Association, 2001. Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings, 2001 (Japanese Version), Tokyo, Japan.

<Appendix> Deviation and Damage Function

1) Deviation and Modified Distribution of Is for Pre-code RC Frame Structures

The following relative frequency distributions of structural seismic index for three different deviations (0.12, 0.15, and 0.18) show that the most frequent seismic index, Is, value is 0.28, and all three distributions have a zero frequency at an Is value of 0.025. As the size of the deviation increases, there is a relatively greater frequency of higher values of Is.

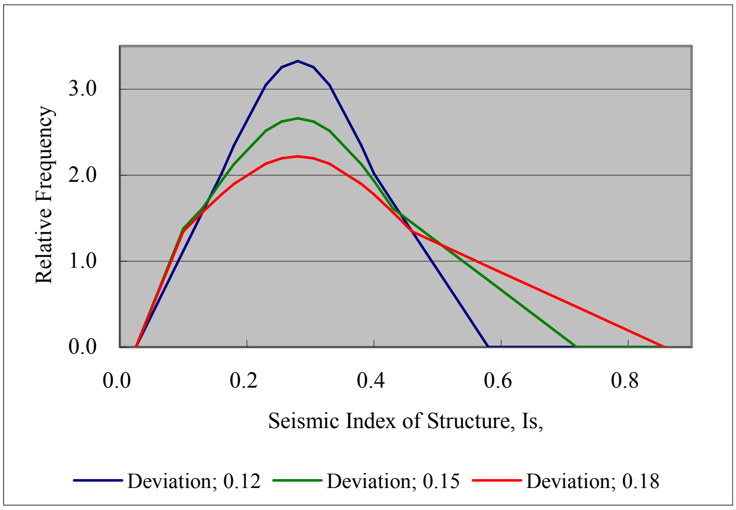


Figure 6-A1 Distribution of Seismic Index of Structure, Is, and Deviation

2) Damage Function

A Heavily Damaged Ratio distribution as produced by the Damage Function for an Is value of 0.28 for deviations of 0.12, 0.15 and 0.18 is shown;

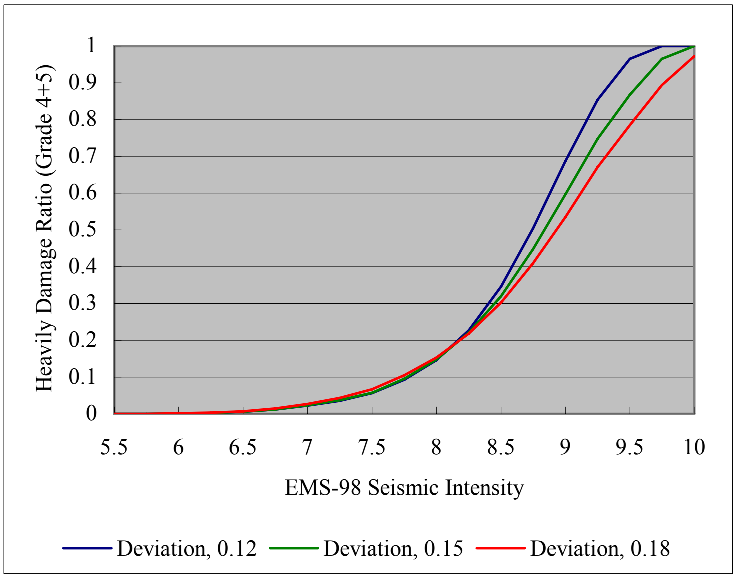


Figure 6-A2 Damage Function for Different Deviation with Same, Is, of Peak Value of Distribution

There was no significant difference up to intensity 8. There was a clear difference at intensity 9 and above because of the difference in the maximum values of the various distributions of the seismic index of structure.

6-1-4 Estimated Damage

(1) Inventory estimation

The building inventory was estimated based on the flowchart in Figure 6-14. First the number of buildings in each 250 m grid was counted based on the building polygon included in the GIS data that was purchased from URBANIS and subsequently revised by the Study Team (Figure 6-15). The buildings were attributed to the 250 m grid sector in which the center of the polygon was located.

The ratios of building types in each commune were estimated from the inventory survey. The ratios of building types in the commune that contains the grid sector were used to estimate the number of buildings of each class in each grid sector.

The distribution of buildings by each classification is shown in Figure 6-16.

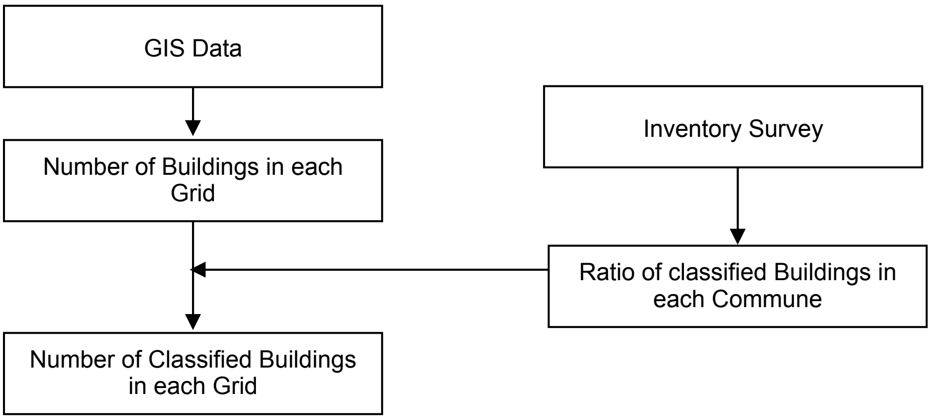


Figure 6-14 Flowchart of building inventory distribution

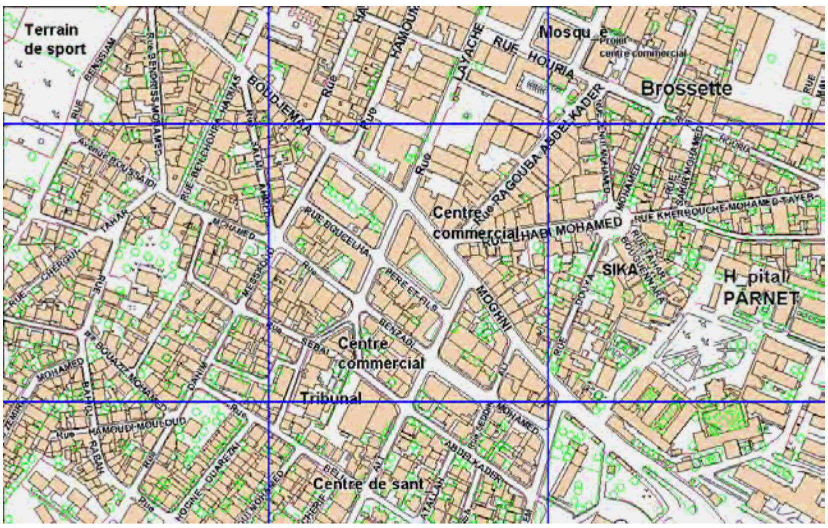


Figure 6-15 Example of building polygon and 250 meter grid boundary

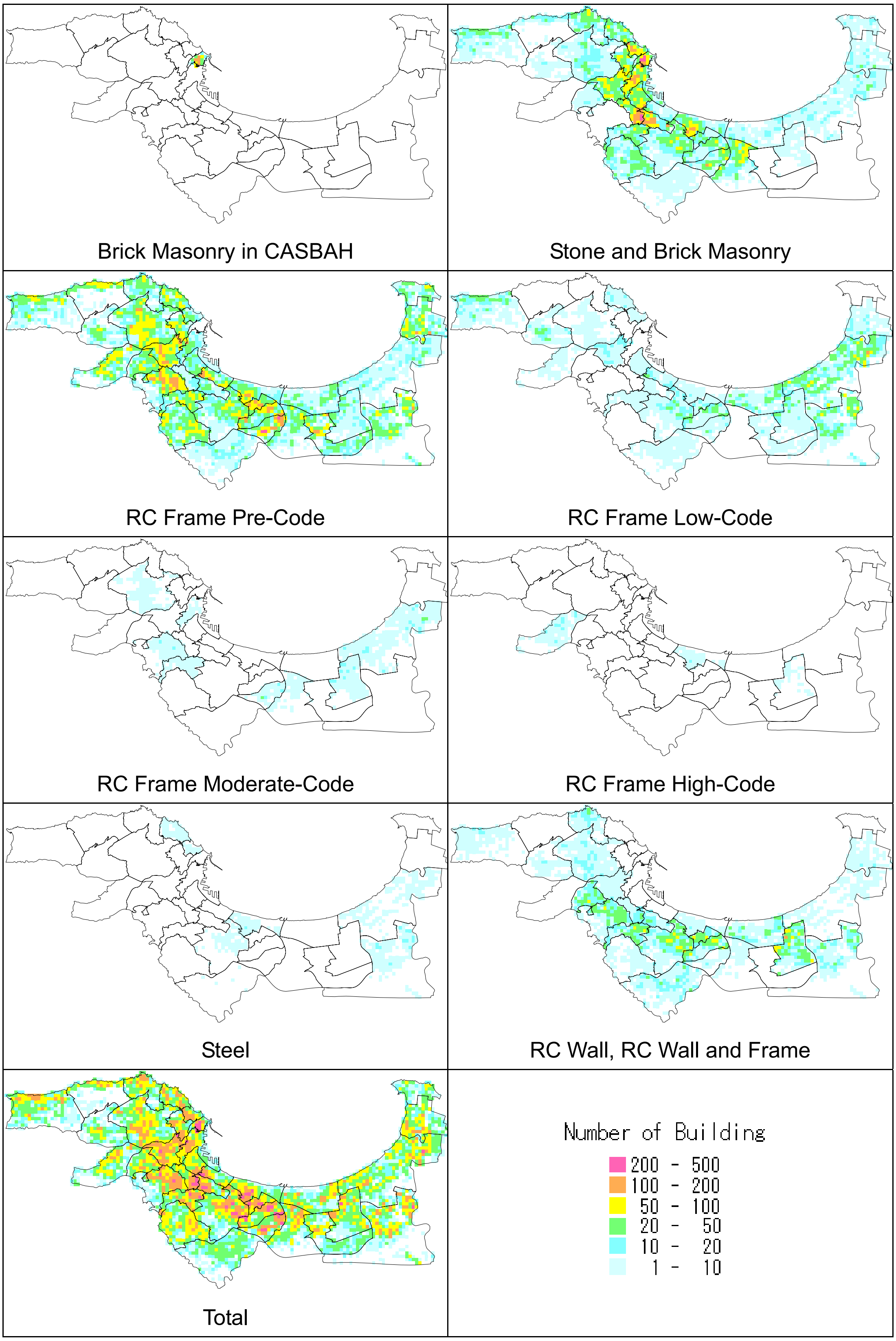


Figure 6-16 Building Distribution by class

(2) Damage estimation

Damage to buildings was estimated for two scenario earthquakes. The estimated number of heavily damaged buildings is shown in Table 6-7. In Table 6-7, the degree of damage from the 2003 Boumerdes earthquake was reproduced with this methodology and is also included. The distribution of heavily damaged buildings is shown in Figure 6-17 and the ratio of heavily damaged buildings is shown in Figure 6-18. The characteristics of damage expected to be caused by the two scenario earthquakes are as follows:

- Khair al Din Scenario Earthquake

  The total number of heavily damaged buildings is estimated to be 56,000 and heavily damaged dwelling units number 100,000. The damage ratio is around 36 %. More than 4,600 buildings could be heavily damaged in BORDJ EL KIFFAN. Almost half of the buildings in EL MOURADIA, EL MADANIA, EL BIAR, EL HARRACH, HUSSEIN DEY and AIN BENIAN could be heavily damaged.

- Zemmouri Scenario earthquake

  The total number of heavily damaged buildings is estimated to be 29,000 and heavily damaged dwelling units number 47,000. The damage ratio is around 17 to 19 %. The damage is concentrated in the eastern area. Almost half of the buildings in DAL EL BEIDA could be heavily damaged.

Table 6-7 Building Damage

ID	Commune Name	Inventory		Khair al Din Scenario eq.				Zemmouri Scenario eq.				2003 Boumerdes eq.			
		Building	Housing Unit	Building		Housing Unit		Building		Housing Unit		Building		Housing Unit	
1601	ALGER CENTRE	3,396	16,219	1,395	41%	6,662	41%	379	11%	1,808	11%	98	3%	468	3%
1602	SIDI M'HAMED	2,206	13,863	922	42%	5,795	42%	235	11%	1,475	11%	65	3%	411	3%
1603	EL MADANIA	3,124	8,788	1,435	46%	4,037	46%	492	16%	1,384	16%	148	5%	417	5%
1604	HAMMA EL ANNASSER	2,169	8,594	834	38%	3,305	38%	265	12%	1,049	12%	79	4%	312	4%
1605	BAB EL OUED	1,884	13,184	616	33%	4,311	33%	155	8%	1,081	8%	28	1%	198	1%
1606	BOLOGHINE	2,933	6,643	899	31%	2,037	31%	212	7%	479	7%	39	1%	89	1%
1607	CASBAH	2,739	10,175	1,067	39%	3,963	39%	282	10%	1,049	10%	57	2%	211	2%
1608	OUED KORICHE	2,585	8,823	978	38%	3,337	38%	246	10%	838	10%	63	2%	216	2%
1609	BIR MOURAD RAIS	4,696	6,927	1,249	27%	1,842	27%	331	7%	488	7%	92	2%	135	2%
1610	EL BIAR	7,408	8,616	3,393	46%	3,946	46%	820	11%	953	11%	249	3%	290	3%
1611	BOUZAREAH	9,804	11,098	2,633	27%	2,980	27%	454	5%	514	5%	80	1%	91	1%
1612	BIRKHADEM	6,459	8,455	1,852	29%	2,424	29%	617	10%	807	10%	187	3%	244	3%
1613	EL HARRACH	4,560	7,296	2,076	46%	3,321	46%	1,555	34%	2,487	34%	499	11%	799	11%
1615	OUED SMAR	3,455	3,092	1,339	39%	1,199	39%	1,352	39%	1,210	39%	411	12%	368	12%
1616	BOUROUBA	4,808	9,385	1,892	39%	3,692	39%	1,259	26%	2,457	26%	431	9%	841	9%
1617	HUSSEIN DEY	4,630	8,015	2,155	47%	3,730	47%	1,024	22%	1,772	22%	329	7%	569	7%
1618	KOUBA	8,940	15,913	2,884	32%	5,133	32%	1,195	13%	2,127	13%	355	4%	632	4%
1619	BACH DJERAH	6,041	15,048	1,895	31%	4,720	31%	1,119	19%	2,787	19%	378	6%	941	6%
1620	DAR EL BEIDA	8,094	6,095	2,941	36%	2,215	36%	3,848	48%	2,897	48%	1,336	17%	1,006	17%
1621	BAB EZZOUAR	5,138	13,544	1,490	29%	3,928	29%	1,531	30%	4,036	30%	418	8%	1,103	8%
1622	BEN AKNOUN	3,299	3,391	1,009	31%	1,037	31%	166	5%	171	5%	42	1%	43	1%
1623	DELY BRAHIM	3,813	4,526	1,309	34%	1,554	34%	198	5%	235	5%	51	1%	60	1%
1624	HAMMAMET	2,223	3,283	687	31%	1,015	31%	98	4%	145	4%	15	1%	23	1%
1625	RAIS HAMIDOU	3,364	3,169	1,047	31%	987	31%	200	6%	188	6%	35	1%	33	1%
1626	DJASR KACENTINA	3,458	12,639	785	23%	2,870	23%	424	12%	1,549	12%	132	4%	484	4%
1627	EL MOURADIA	3,277	5,017	1,675	51%	2,565	51%	512	16%	783	16%	157	5%	241	5%
1628	HYDRA	6,980	6,080	1,967	28%	1,714	28%	417	6%	363	6%	111	2%	97	2%
1629	MOHAMMADIA	4,321	6,749	1,671	39%	2,610	39%	1,304	30%	2,036	30%	369	9%	576	9%
1630	BORDJ EL KIFFAN	10,915	14,375	4,637	42%	6,107	42%	4,911	45%	6,468	45%	1,822	17%	2,400	17%
1631	EL MAGHARIA	2,643	4,559	974	37%	1,680	37%	493	19%	851	19%	153	6%	264	6%
1632	BENI MESSOUS	2,254	2,630	821	36%	958	36%	125	6%	146	6%	33	1%	38	1%
1639	BORDJ EL BAHRI	4,724	4,030	1,799	38%	1,535	38%	2,022	43%	1,724	43%	738	16%	629	16%
1640	EL MARSA	1,330	1,366	504	38%	518	38%	556	42%	571	42%	217	16%	223	16%
1644	AIN BENIAN	6,362	8,252	2,986	47%	3,873	47%	385	6%	499	6%	108	2%	140	2%
Total		154,032	279,838	55,817	36%	101,600	36%	29,176	19%	47,430	17%	9,327	6%	14,592	5%

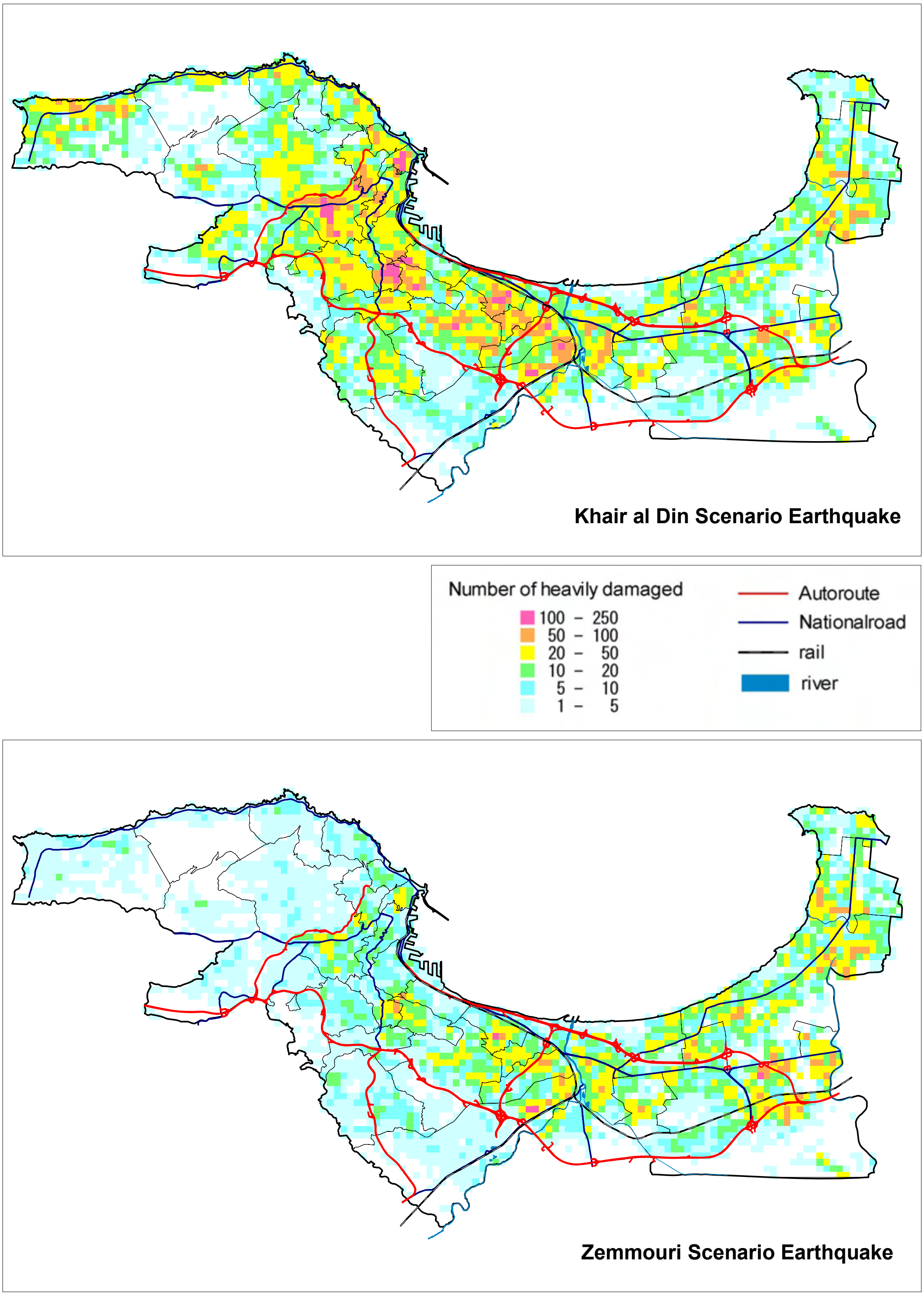


Figure 6-17 Number of Heavily Damaged Buildings

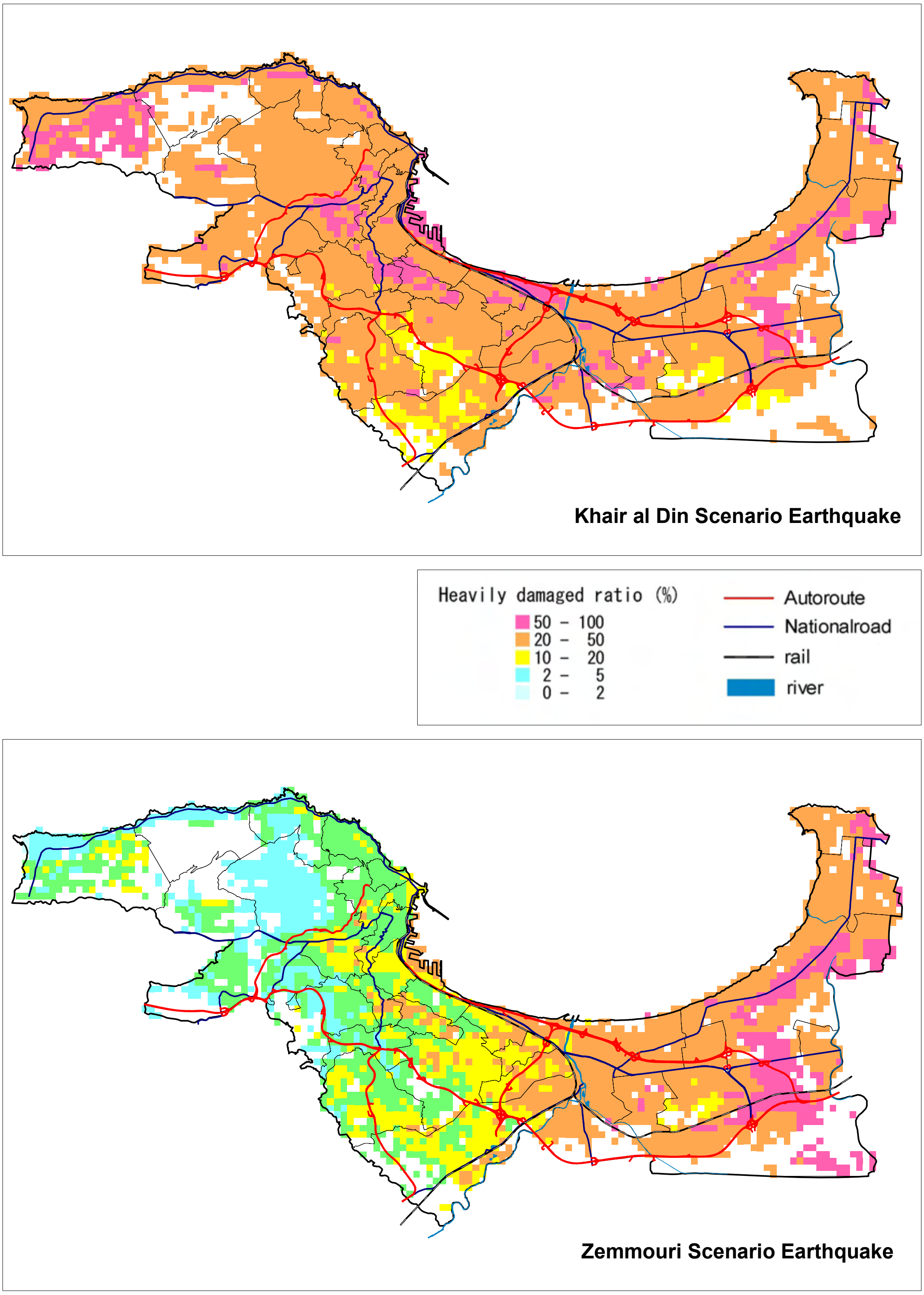


Figure 6-18 Ratio of Heavily Damaged Buildings

6-2 Human Casualties

In an earthquake, human casualties occur due to a variety of causes. Death due to crushing under a collapsing building, falling of large heavy furniture, burns due to fire, drowning as a result of tsunami, and heart attack due to shock are examples. Among these, human casualties due to building collapse are a general phenomena observed in all areas subject to earthquake disasters. The main cause of casualties may differ from site-to-site depending on the ground, buildings and the social environment. In Algeria, the main cause of human casualties has been and is expected to be the collapse of buildings, as exemplified by the 2003 Boumerdes earthquake.

6-2-1 Methodology

(1) Damage Data from Past Earthquakes

The relationship between building damage and human casualties differ depending on the region. The differences in building structure and residential condition may also have an affect. Therefore, it is desirable to define the damage function based on earthquake hazard in a neighboring region. In this Study, the number of human casualties and damaged buildings as a result of recent earthquake disasters in Algeria were collected from various documents and are summarized in Table 6-8.

In an analysis of the damage function, it is important to recognize the difference between a “building” and a “dwelling unit”. In urbanized areas, e.g. Algiers, there are many apartment houses, each of which contains many dwelling units. The effect of the collapse of one apartment with multiple dwelling units would be greater than the collapse of one individual house. Therefore, the number of damaged dwelling units is a better indicator than that of damaged buildings when estimating human casualties.

In Table 6-8 the number of structures damaged as a result of the 2003 Boumerdes earthquake represents the damaged dwelling units as assessed by CTC investigation. Other estimates of the damaged buildings can also be obtained from the CGS investigation. Unlike the Boumerdes earthquake, the areas affected by other earthquakes were rural and most buildings were individual houses. Therefore the number of damaged buildings in earthquakes other than the Boumerdes earthquake is treated as being equal to the number of damaged dwelling units in the following analysis.

(2) Analysis Unit

Another parameter to be considered in the analysis is the building damage density. If 1,000 buildings collapse in an earthquake in one wilaya, many people in the wilaya will be killed. However, if 1,000 buildings collapse in one commune, more people will be killed in the commune because the disaster situation in the neighboring commune would be almost the same and, consequently, the rescue operation will be spread thinly over a large area and thereby degraded. That is to say that the projected number of human casualties for one building collapse is different depending on the unit area under analysis. Therefore the unit area in the analysis of the damage function should be compatible with the unit area in the damage estimation. The human casualties are to be estimated by commune in this Study, therefore the commune is the desirable unit in the damage function analysis. Also the damage function depends on local conditions, e.g. building density, building structure, and rescue system, so the damage data in the target study area is preferable for damage function nalysis.

(3) Formulation of the Damage Function

Algiers, the Study area, experienced major seismic damage in 2003 from the Boumerdes earthquake and the damage record of this recent earthquake is naturally first-rate information. Since the beginning of this Study the Study Team has tried to collect data on the human casualties caused by the 2003 earthquake in Wilaya Algiers and Wilaya Boumerdes by commune, however, the only information we could collect was the total number of casualties in Wilaya Algiers from published papers and the number killed in Wilaya Boumerdes by C.A.

Although the available data was not considered to be sufficient, because of the recent experience in Algiers, work on creating a damage function went ahead anyway. The building damage estimation in this Study delineated both the number of heavily damaged buildings and heavily damaged dwelling units, therefore, the number of heavily damaged dwelling units was used as the indicator to estimate the number killed. The relationship between the number killed and the number of heavily damaged dwelling units is shown in Figure 6-19. The damage function in Figure 6-19 was made from these relationships and modified to reproduce the death toll in the Study Area caused by the 2003 earthquake. The relationship between number killed and the number of heavily damaged dwelling units is scattered reflecting the many conditions affecting the outcome, however, most data are included between two thin lines in this figure, which represent double and half of the number estimated from the damage function. This means that the estimated number of casualties calculated by the damage function in Figure 6-19 has a high degree of uncertainty and the actual outcome in the event of a real earthquake could lie anywhere from half to double the number estimated in this function.

The damage function to estimate the number of injured using the number killed as the indicator is shown in Figure 6-20. This function is derived from the same data sets in Table 6-8.

Table 6-8 Casualties and Damage of Buildings by Past Earthquakes in Algeria

Earthquake	Local Time	Wilaya	Circonscription Administrative	Number of Casualty			Number of Damaged Buildings/Dwelling Units			
				Death	Injured	Ref.	Rouge (Grade 5)	Orange (Grade 3+4)	Heavily Damaged *) (Grade 4+5)	Ref.
1965 M'sila & Environs				2	350	1)				
1980 El Asnam	13:25			2,633	8,369		32,000	102,000	73,922	5)
1980 El Asnam Aftershock				2	90					
1987 Chle				1	7					
1989 Chenoua	20:09			22	184		4,055	1,595	4,711	4)
1994 Mascara	2:13			171	289		751	894	1,118	
1999 Ain Temouchent	18:37			22	175		822	930	1,204	
2000 Beni-Ouartilane	21:13			3	60		1,210	4,438	3,034	
2003 Boumerdes	19:44	Boumerdes	Khemis El Khechna	22	3,442	2)3)	506	3,346	1,881	6)
			Boudouaou	239			1,270	5,007	3,328	
			Boumerdes	538			2,370	5,031	4,438	
			Thenia	96			705	3,147	1,998	
			Issers	27			332	2,984	1,558	
			Bordj Menaiel	324			3,585	6,796	6,378	
			Naciria	2			170	1,120	630	
			Baghlia	89			538	1,463	1,139	
			Dellys	129			1,037	2,317	1,989	
		Algiers		883	6,787	3)	11,060	49,580	31,437	6)
		Tizi-ouzou		7	261					
		Bouira		2	127					
		Béjaia		2	3					
		Blida		2	709					
		Médéa		0	121					
2003 Boumerdes Aftershock	18:11			9	200	1)				

*) "Heavily Damaged" means Grade 4+5

"Heavily Damaged" = "Rouge (Grade 5)" + "Orange (Grade 3+4)" * 0.411.

The ratio of "Grade 4/Grade 3+4" = 0.411 was calculated from building damage survey of Boumerdes Earthquake by CGS

Data Source:

1) CRED (Center for Research on the Epidemiology of Disasters, Université Catholique de Louvain, Brussels - Belgium)
2) PC (Civil Defence)
3) Kheir-Eddine Ramdane (2003), ALGER-BOUMERDES, Algeria EARTHQUAKE OF MAY 21, 2003
4) CGS, number of buildings
5) Total damage number of dwelling units was estimated by the Study Team from a sample survey by CGS
6) CTC, dwelling units

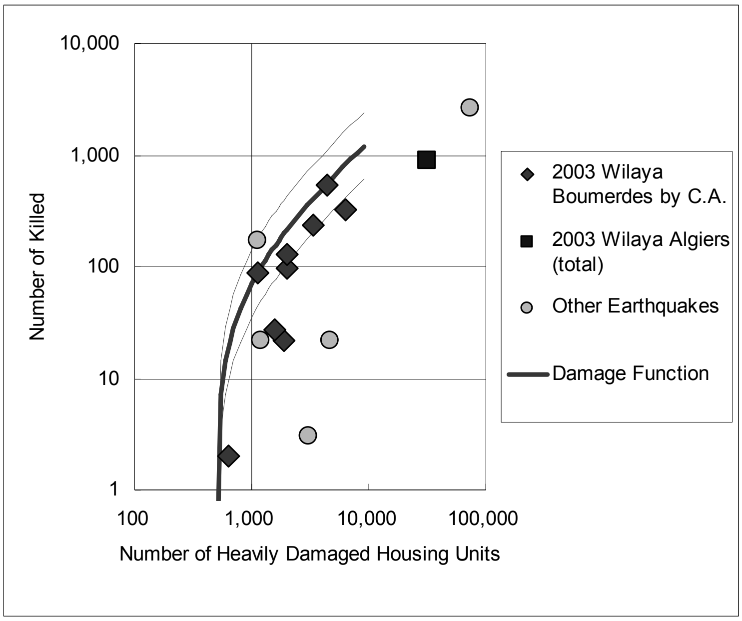


Figure 6-19 Damage Function to Estimate the Number Killed

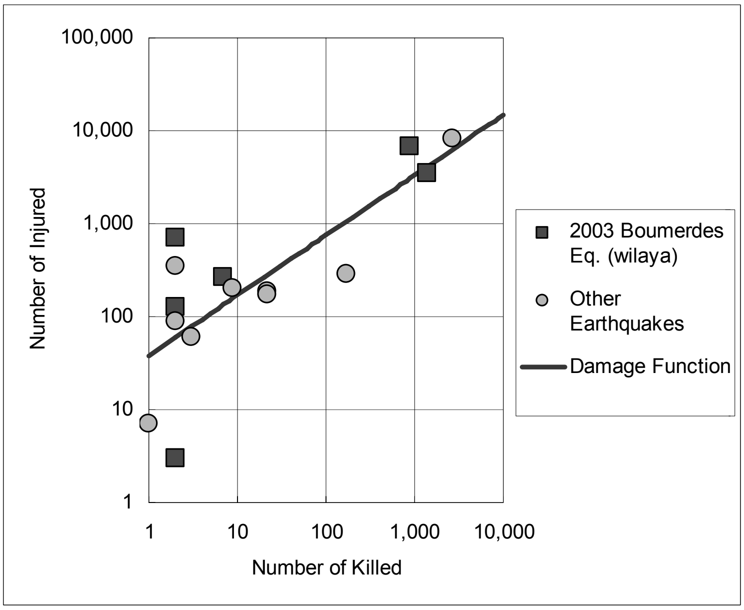


Figure 6-20 Damage Function to Estimate the Number of Injured

6-2-2 Damage Estimation

Human casualties were estimated for two scenario earthquakes. In the estimation, the event is assumed to occur in the evening because the damage function was mainly derived from the 2003 Boumerdes earthquake damages. The major cause of damage is building collapse. In large-scale earthquakes, people may also die from diseases in refugee camps, but these deaths are not included in the assumption.

The estimated number of human casualties and number of homeless people are shown in Table 6-9. The number of homeless people is the people who were previously living in the heavily damaged buildings. In Table 6-9, the damage caused by the 2003 Boumerdes earthquake as reproduced using this methodology is also included. The distribution of the death toll for each commune is shown in Figure 6-21. Characteristics of the damage from the two scenario earthquakes are as follows:

- Khair al Din Scenario Earthquake

The total death toll is estimated at 12,000 and injured people number 550,000. More than 600 people will be killed in ALGER CENTRE, SIDI M'HAMED, KOUBA and BORDJ EL KIFFAN. Almost all the study area will be severely damaged.

- Zemmouri Scenario earthquake

Total death toll is estimated at 4,500 and injured people number 240,000. The damage is concentrated in the eastern area.

Table 6-9 Human Casualties

ID	Commune Name	Population (x1,000)	Khair al Din Scenario eq.			Zemmouri Scenario eq.			2003 Boumerdes eq.		
			Killed (x1,000)	Injured (x1,000)	Homeless (x1,000)	Killed (x1,000)	Injured (x1,000)	Homeless (x1,000)	Killed (x1,000)	Injured (x1,000)	Homeless (x1,000)
1601	ALGER CENTRE	96.3	0.9	3.1	39	0.2	1.1	11	0.0	0.0	3
1602	SIDI M'HAMED	90.5	0.8	2.8	37	0.1	0.9	9	0.0	0.0	3
1603	EL MADANIA	51.4	0.5	2.1	23	0.1	0.9	8	0.0	0.0	2
1604	HAMMA EL ANNASSER	59.2	0.4	1.8	22	0.1	0.6	7	0.0	0.0	2
1605	BAB EL OUED	87.6	0.5	2.2	28	0.1	0.7	7	0.0	0.0	1
1606	BOLOGHINE	43.3	0.2	1.2	13	0.0	0.0	3	0.0	0.0	1
1607	CASBAH	50.5	0.5	2.1	19	0.1	0.6	5	0.0	0.0	1
1608	OUED KORICHE	53.4	0.4	1.9	20	0.0	0.5	5	0.0	0.0	1
1609	BIR MOURAD RAIS	43.3	0.2	1.1	11	0.0	0.0	3	0.0	0.0	1
1610	EL BIAR	52.6	0.5	2.1	24	0.1	0.6	6	0.0	0.0	2
1611	BOUZAREAH	69.2	0.4	1.7	18	0.0	0.1	3	0.0	0.0	1
1612	BIRKHADEM	55.1	0.3	1.4	16	0.0	0.4	5	0.0	0.0	2
1613	EL HARRACH	48.2	0.4	1.8	22	0.3	1.5	16	0.0	0.4	5
1615	OUED SMAR	21.4	0.1	0.7	8	0.1	0.8	8	0.0	0.0	3
1616	BOUROUBA	77.5	0.5	2.0	30	0.3	1.5	20	0.0	0.5	7
1617	HUSSEIN DEY	49.9	0.5	2.0	23	0.2	1.1	11	0.0	0.2	4
1618	KOUBA	105.3	0.7	2.5	33	0.2	1.3	14	0.0	0.3	4
1619	BACH DJERAH	90.1	0.6	2.4	28	0.3	1.6	16	0.1	0.6	6
1620	DAR EL BEIDA	44.8	0.2	1.3	16	0.3	1.7	21	0.1	0.6	7
1621	BAB EZZOUAR	92.2	0.5	2.1	26	0.5	2.1	27	0.1	0.7	7
1622	BEN AKNOUN	19.4	0.1	0.6	6	0.0	0.0	1	0.0	0.0	0
1623	DELY BRAHIM	30.6	0.1	1.0	10	0.0	0.0	2	0.0	0.0	0
1624	HAMMAMET	19.7	0.1	0.6	6	0.0	0.0	1	0.0	0.0	0
1625	RAIS HAMIDOU	21.5	0.1	0.6	7	0.0	0.0	1	0.0	0.0	0
1626	DJASR KACENTINA	82.7	0.3	1.6	18	0.1	1.0	10	0.0	0.0	3
1627	EL MOURADIA	29.5	0.3	1.5	15	0.0	0.4	5	0.0	0.0	1
1628	HYDRA	35.7	0.2	1.1	10	0.0	0.0	2	0.0	0.0	1
1629	MOHAMMADIA	42.1	0.3	1.5	16	0.2	1.2	12	0.0	0.2	4
1630	BORDJ EL KIFFAN	103.7	0.8	2.9	43	0.8	3.0	46	0.3	1.4	17
1631	EL MAGHARIA	30.5	0.2	1.0	11	0.0	0.5	6	0.0	0.0	2
1632	BENI MESSOUS	17.5	0.1	0.6	6	0.0	0.0	1	0.0	0.0	0
1639	BORDJ EL BAHRI	27.9	0.1	1.0	10	0.2	1.1	12	0.0	0.2	4
1640	EL MARSA	8.8	0.0	0.1	3	0.0	0.2	4	0.0	0.0	1
1644	AIN BENIAN	52.3	0.5	2.1	24	0.0	0.0	3	0.0	0.0	1
Total		1,803.3	12.0	54.7	642	4.6	25.2	311	0.6	5.0	97

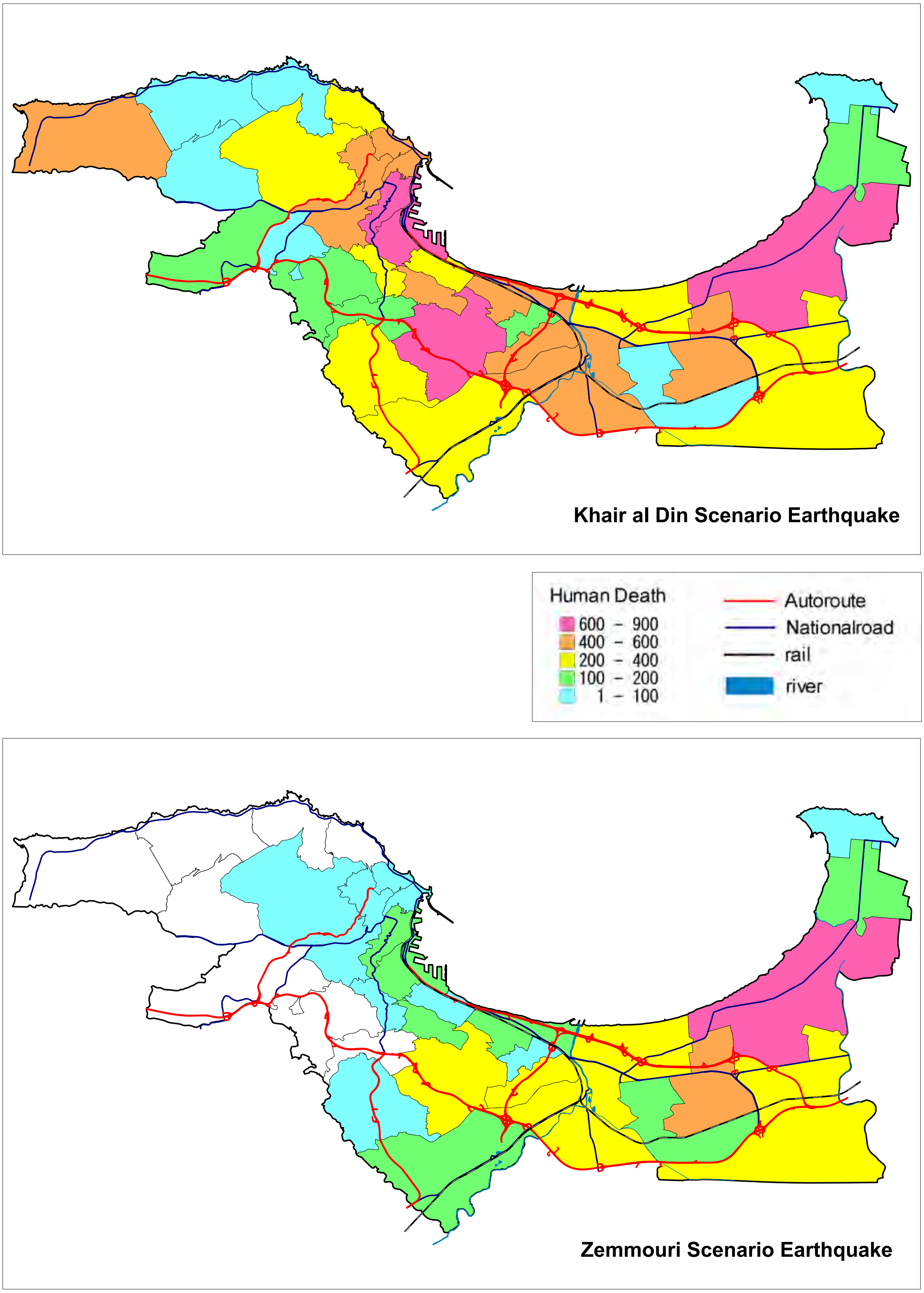


Figure 6-21 Number of Dead

6-3 Infrastructure and Lifelines

When infrastructure suffers heavy damage due to a major earthquake, emergency relief / rescue efforts will be disrupted and various social functions frozen for a long period.

The following 3 types of infrastructure are considered in this section:

1. Bridges (6-3-1)
2. Ports (6-3-2)
3. Airports (6-3-3)

Damage to infrastructure due to a scenario earthquake was estimated based on an empirical approach with a damage estimation method selected by the joint efforts of the JICA sturdy team and the counterparts. The JICA study team and counterparts verified the method using past earthquake damage records in Algeria.

Lifeline facilities are indispensable in the modern urban lifestyle and damage to lifeline facilities due to earthquakes impacts strongly on society.

The following 5 types of lifelines are considered in this section:

1. Water Supply (6-3-4)
2. Sewerage (6-3-5)
3. Electric Power Supply (6-3-6)
4. Gas Supply (6-3-7)
5. Telecommunications (6-3-8)

The damage function of a lifeline has been formulated in a few countries and/or regions such as Japan and California. It is rare that the quantitative lifeline damage conditions are announced, because lifelines are almost always private facilities. Consequently, the damage estimation of lifelines is generally conducted by selecting damage functions for Japan or California, which are based on damage records due to past earthquakes in these limited areas.

A possible damage estimation method selected by the JST and the counterpart is described in this section.

Damage estimation of infrastructure and lifelines is examined on 2 scenario earthquakes, the “Khair al Din” and the “Zemmouri”.

6-3-1 Bridges

Failure of a bridge structure can result in extensive disruption to the traffic system even though each failure is limited to a particular point in the road system. For instance, although the road itself is safe, if some bridges are destroyed, the road network will not function and emergency relief / rescuers will be unable to reach sites where assistance is needed. In addition, the road network (in terms of reconstruction) will be useless because bridge repairs are extremely long-term. Thus, destruction of bridges should be prevented as much as possible.

(1) Method

The purpose of the damage estimation of bridges is to highlight and note specific bridges in order to mitigate disruption to traffic. Also the falling of a girder can result in serious impacts on the road system. Therefore, a methodology proposed by Kubo / Katayama (hereinafter referred to as "Katayama's method") is selected in this study. This methodology is very effective in evaluating bridges from the viewpoint of falling girders and is used as a first screening. An outline of this evaluation system is shown in Figure 6-22.

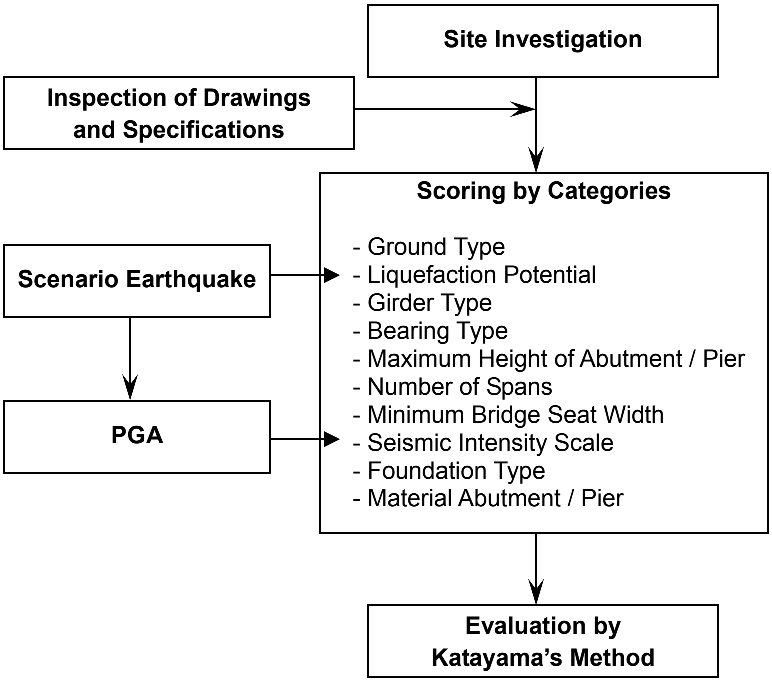


Figure 6-22 Flowchart of Stability Analysis of Bridges

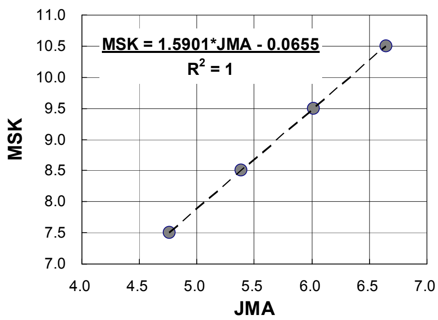
In Katayama's method, 10 items likely to affect the probability of a girder falling are studied. Each item consists of a number of categories selected without complex calculations. A score chart for bridge stability analysis is shown in Table 6-10. The category described in Table 6-10 was adjusted from the original taking into account the conditions of the study area.

Table 6-10 Score Chart for Stability Analysis of Bridges

Item		Category	Category Score
Ground Type		Stiff / Hard: Slightly / No Weathered Rock	0.5
		Medium: Weathered / Moderately Weathered Rock	1.0
		Soft: Deposited Soil / Diluvium	1.5
		Very Soft: Deposited Soil / Alluvium	1.8
Liquefaction Potential		No Liquefaction	1.0
		Possible Liquefaction: $0 \leq P_L < 15$	1.5
		Liquefaction: $15 \leq P_L$	2.0
Girder Type		Arch or Rigid Frame	1.0
		Continuous	2.0
		Simple	3.0
Bearing Type		With Specific Device (prevent girder from falling)	0.6
		Bearing (with clear design concept)	1.0
		Exist Two Bearing (it can move axial direction)	1.15
		Others (no bearing, etc)	1.1
	Aseismic System*	System for Prevention of girder Falling	0.6
		Bearing with Rubber	0.9
Max. Height of Abut./Pier		Less Than 5 m	1.0
		5 to 10 m	1.35
		More Than 10m	1.7
Number of Spans		1 Span	1.0
		2 Spans or More	1.75
Min. Bridge Seat Width		Wide: 70 cm or Wider	0.8
		Narrow: Less Than 70 cm	1.2
		No Seat: 0 cm	1.1
Seismic Intensity Scale (MSK)**		MSK < 7.885 (JMA: less than 5.0)	1.0
		7.885 ≤ MSK < 8.680 (JMA: 5.0 to less than 5.5)	2.1
		8.680 ≤ MSK < 9.475 (JMA: 5.5 to less than 6.0)	2.4
		9.475 ≤ MSK < 10.270 (JMA: 6.0 to less than 6.5)	3.0
		10.270 ≤ MSK (JMA: 6.5 and more than 6.5)	3.5
Foundation Type		Pile Bent	1.4
		Others	1.0
Material of Abut./Pier		Plain Concrete or Masonry	1.4
		Reinforced Concrete or Others	1.0

* If aseismic system (system for preventing girder from falling or bearing with rubber) is applied, one of the above mentioned aseismic systems is selected regardless the bearing type.

** The relationship between MSK and ground acceleration is proposed in this Study based on the past records, while JMA is related to ground acceleration. Here, the relationship between JMA and MSK via acceleration is proposed as shown in the following diagram



A category score, shown in Table 6-10, is given to each category as a weighting factor.

The result can then be determined by substituting the data into the following equation:

$$y_i = \prod_{j=1}^{N} \prod_{k=1}^{M_j} X_{jk}^{\delta_i(jk)}$$

where,

y_i : Predictors of damage degrees of i-th bridges

N : Number of all items

M_j : Number of categories of j-th items

$\delta_i(jk)$: Dummy variable ($\delta_i(jk)$ = 1; when the characteristics of the i-th bridge correspond to the category k in the item, $\delta_i(jk)$ = 0; otherwise)

X_{jk} : Category score for k-th category of the j-th item

$\prod_{j=1}^{N}$: Multiplication sign from 1 to N-th value

The threshold value of the predictor to estimate damage grade of bridges is based on 30 samples of damaged bridges observed during 3 earthquakes in Japan (1923 Kanto, 1948 Fukui, 1964 Niigata) as shown in Table 6-11. In this study, the JST and the counterpart verified this method using relating records of the Boumerdes Earthquake. As a result, the definition of the class of damage grade and the threshold value were modified (refer to following section for details).

Table 6-11 Definition of Damage Grade of Bridges

Class of damage grade		Original threshold value of predictor	Modified threshold value of predictor
A	- High probability of girders falling - Generates huge deformation - Impossible to use for long term and requires reconstruction	30 and more	30 and more
B	- Moderate probability of girders falling - Generates deformation - Impossible to use temporarily and requires repairing / rehabilitation	26 to less than 30	22 to less than 30
C	- Low probability of girder falling- Generates small deformation - Possible to basically use after inspection	less than 26	less than 22

(2) Verification of Method

Falling of bridge girders was not reported in the Boumerdes Earthquake; however, some bridges suffered damage such as deformations, cracks and so on.

In this chapter, verification of the method and the threshold value is examined in light of the damage to the SEBAO Bridge in the Wilaya of Boumerdes and EL HARRACH Bridge in the Wilaya of Algiers, because we obtained the required information for the method from the website (http://www.kedm.bosai.go.jp) and the counterpart, and the above mentioned bridges had different damage grades.

Table 6-12 shows summary of the verification for Katayama's method.

Table 6-12 Summary of Verification of Katayama's Method

Bridge	Case by MSK Scale	Total Score	Class of Damage Grade		Verification
			Katayama's Method*	Actual Damage	
SEBAO	1	25.7	B	B	Falling of the girders did not occur, but displacement was generated. Probability of falling girders is evaluated by the actual damage as class "B" that is very close to class "A". Hence, the result of the method shows a good match for the actual damage.
	2	29.4	B		
	3	36.7	A		
EL HARRACH	1	19.3	C	B	Falling of the girders did not occur, and slight displacement was generated. Probability of falling girders is evaluated by the actual damage as class "B" that is very close to class "C". Hence, the result of the method shows a good match for the actual damage.
	2	22.1	B		
	3	27.6	B		

*Threshold value for evaluation of the class applies the modified value.

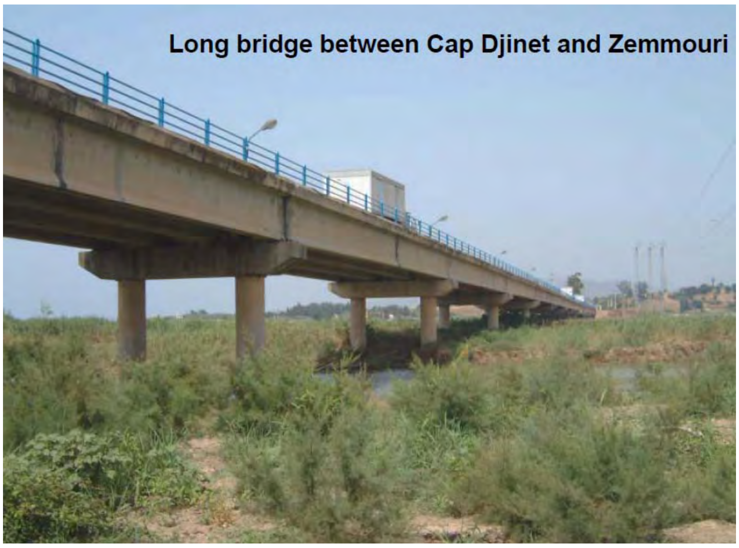
As the above table shows, the results of Katayama's method with modified threshold values and the actual damage to each bridge were well matched. This indicates that Katayama's method is suitable for the bridge damage estimation.

The calculation and the actual damage condition for each bridge are descried in detail below.

1) SEBAO Bridge

(A) Katayama's Method

Structures of the SEBAO Bridge (refer to Figure 6-23) and the scores in relation to them are shown in Table 6-13.



(This photo was extracted from "Short Report, 1st reconnaissance team from JAEE, JSCE, JGS and AIJ")

Figure 6-23 View of SEBAO Bridge

Table 6-13 Structure of SEBAO Bridge for Katayama's Method

Item	Category	Category Score
Girder Type	Simple	3.0
Bearing Type	Bearing and System for Prevention of Girders Falling	0.6
Max. Height of Abut./Pier	5 to 10 m	1.35
Number of Spans	2 Spans or More	1.75
Min. Bridge Seat Width	Wide: 70 cm or Wider	0.8
Foundation Type	Others	1.0
Material of Abut./Pier	Reinforced Concrete or Others	1.0

Geological / seismic condition at site is shown in Table 6-14.

The ground at the site is alluvial soil because the bridge is across a river in a lowland area.

Liquefaction occurred at the Boumerdes Earthquake as shown in Figure 6-24. Lateral movement / displacement at the ground surface appeared in many places around the bridge, thus the liquefaction potential index (P_L) is estimated as more than 15.

MSK intensity scale at the site was reported as 9, this indicates that the value there was in the range from 8.5 to 9.5. Hence, 3 categories for the seismic intensity scale called Case 1, Case2 and Case 3 were selected as shown in Table 6-14.

(This photo was extracted from "Short Report, 1st reconnaissance team from JAEE, JSCE, JGS and AIJ")

Figure 6-24 Lateral Ground Movement at a Pier of SEBAO Bridge

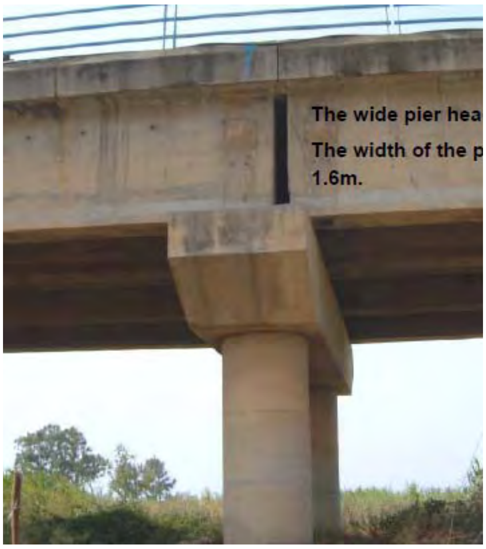
Table 6-14 Geological and Seismic Condition of SEBAO Bridge for Katayama's Method

Item	Category		Category Score
Ground Type	Very Soft: Deposit Soil / Alluvium		1.8
Liquefaction Potential	Liquefaction: 15 ≤ PL		2.0
Seismic Intensity Scale (MSK)	MSK = 9	Case 1: 7.885 ≤ MSK < 8.680	2.1
		Case 2: 8.680 ≤ MSK < 9.475	2.4
		Case 3: 9.475 ≤ MSK < 10.270	3.0

The total score of each case was 25.7 (Case 1), 29.4 (Case 2) and 36.7 (Case 3). Consequently, the class of damage grade based on Katayama's method is judged as class "B" (moderate probability) or "A" (high probability).

(B) Actual Damage Condition

The report of the actual damage to the SEBAO bridge showed that some girders were displaced due to movement of some piers of around 50 cm or less (refer to Figure 6-25), however, the girders did fall off. If no prevention system or less seat width was applied and / or a much more intense earthquake occurred, the girders might have fallen down.



(This photo was extracted from "Short Report, 1st reconnaissance team from JAEE, JSCE, JGS and AIJ")

Figure 6-25 Displacement of a Girder and Lateral Movement of a Pier of SEBAO Bridge

Hence, the damage grade of the SEBAO Bridge is evaluated as class "B" (moderate probability) that is very close to class "A" based on the above mentioned damage.

2) EL HARRACH Bridge

(A) Katayama's Method

Structures of the EL HARRACH Bridge (refer to Figure 6-26) and the score in relation to them are shown in Table 6-15.

Figure 6-26 View of EL HARRACH Bridge

Table 6-15 Structure of EL HARRACH Bridge for Katayama's Method

Item	Category	Category Score
Girder Type	Simple	3.0
Bearing Type	Bearing with Rubber	0.9
Max. Height of Abut./Pier	5 to 10 m	1.35
Number of Spans	2 Spans or More	1.75
Min. Bridge Seat Width	Wide: 70 cm or Wider	0.8
Foundation Type	Others: Pile	1.0
Material of Abut./Pier	Reinforced Concrete or Others	1.0

Geological / seismic condition at site is shown in Table 6-16.

The ground at the site is alluvial soil because the bridge is across a river in a lowland area.

Liquefaction did not occur at the Boumerdes Earthquake, thus the liquefaction potential is judged as No Liquefaction.

The intensity on the MSK scale at the site was reported as 9, this indicates that the value was in the range from 8.5 to 9.5. Hence, 3 categories for the seismic intensity scale of Case 1, Case2 and Case 3 were selected as shown in Table 6-16.

Table 6-16 Geological and Seismic Condition of EL HARRACH Bridge for Katayama's Method

Item	Category		Category Score
Ground Type	Very Soft: Deposit Soil / Alluvium		1.8
Liquefaction Potential	No Liquefaction		2.0
Seismic Intensity Scale (MSK)	MSK = 9	Case 1: 7.885 ≤ MSK < 8.680	2.1
		Case 2: 8.680 ≤ MSK < 9.475	2.4
		Case 3: 9.475 ≤ MSK < 10.270	3.0

The total score of each case is 19.3 (Case 1), 22.1 (Case 2) and 27.6 (Case 3). Consequently, the class of damage grade based on Katayama's method is judged as class "C" (low probability) or "B" (moderate probability).

(B) Actual Damage

The report of the actual damage to the EL HARRACH Bridge showed that some girders were slightly displaced and cracks generated (refer to Figure 6-27), however, the girders did not fall off.

Figure 6-27 Displacement of a Girder of EL HARRACH Bridge

Hence, the damage grade of the SEBAO Bridge is evaluated as class "B" (moderate probability) that is very close to class "C" based on the above mentioned damage condition.

(3) Result

Table 6-17 shows a summary of the damage estimation. Figure 6-28 and Figure 6-29 show the location map of probability of bridges with falling girders for Khair al Din and Zemmouri, respectively.

Table 6-17 Summary of Bridge Damage Estimation

Class of Damage Grade	Number of Bridges [Ratio (%)]	
	Scenario Earthquake	
	Khair al I Din	Zemmouri
A: High Probability	3 [2.0 %]	4 [2.7 %]
B: Moderate Probability	19 [12.9 %]	7 [4.7 %]
C: Low Probability	126 [85.1 %]	137 [92.6 %]
Total	148	148

Table 6-18 shows the score of class "A" bridges and class "B" bridges.

Table 6-18 Summary of Total Score of Class “A” and “B”

Bridge Code	Khair al Din		Zemmouri	
	Total Score	Class	Total Score	Class
16130310	40	A	40	A
16290103	34	A	30	A
16130213	33	A	33	A
16170117	29	B	23	B
16010411	27	B	(< 22)	(C)
16290101	27	B	24	B
16290102	27	B	24	B
16300301	27	B	45	A
16020402	23	B	(< 22)	(C)
16020403	23	B	(< 22)	(C)
16020404	23	B	(< 22)	(C)
16170102	23	B	(< 22)	(C)
16170103	23	B	(< 22)	(C)
16170106	23	B	(< 22)	(C)
16170108	23	B	(< 22)	(C)
16170111	23	B	(< 22)	(C)
16170112	23	B	(< 22)	(C)
16170113	23	B	(< 22)	(C)
16260402	23	B	(< 22)	(C)
16130207	22	B	22	B
16130208	22	B	22	B
16160202	22	B	22	B
16200212	(< 22)	(C)	24	B

[Photograph of Class “A” Bridges]

16130310

16290103

16130213

16300301

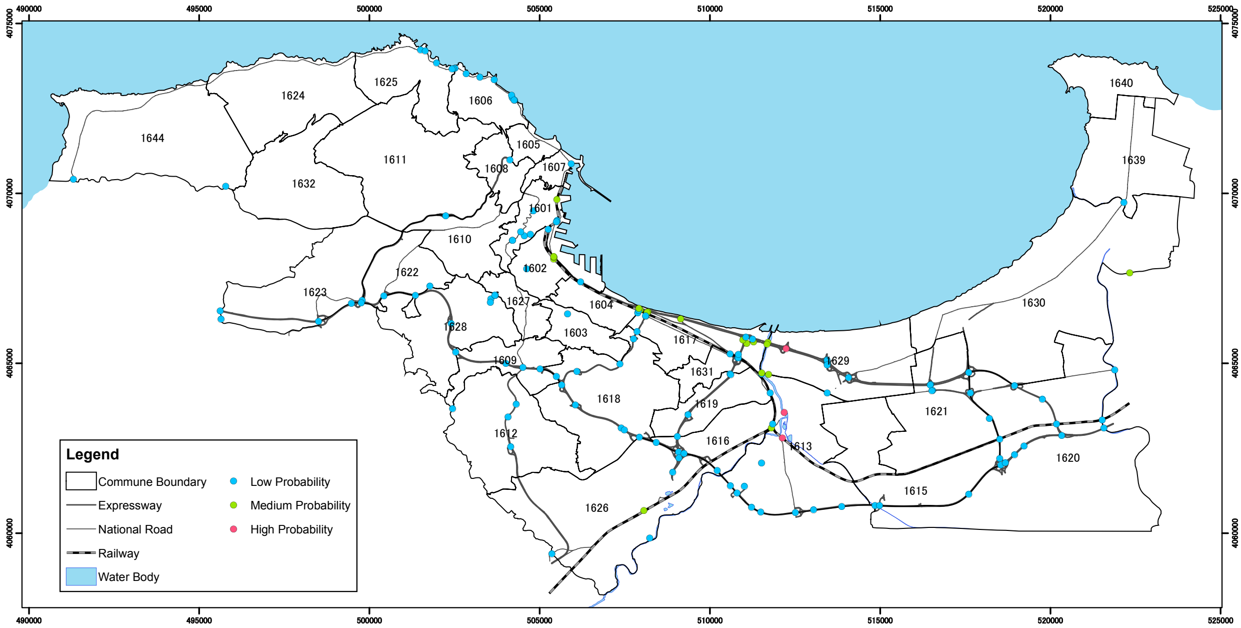


Figure 6-28 Location Map of Probability of Bridges with Falling girders: Khair al Din

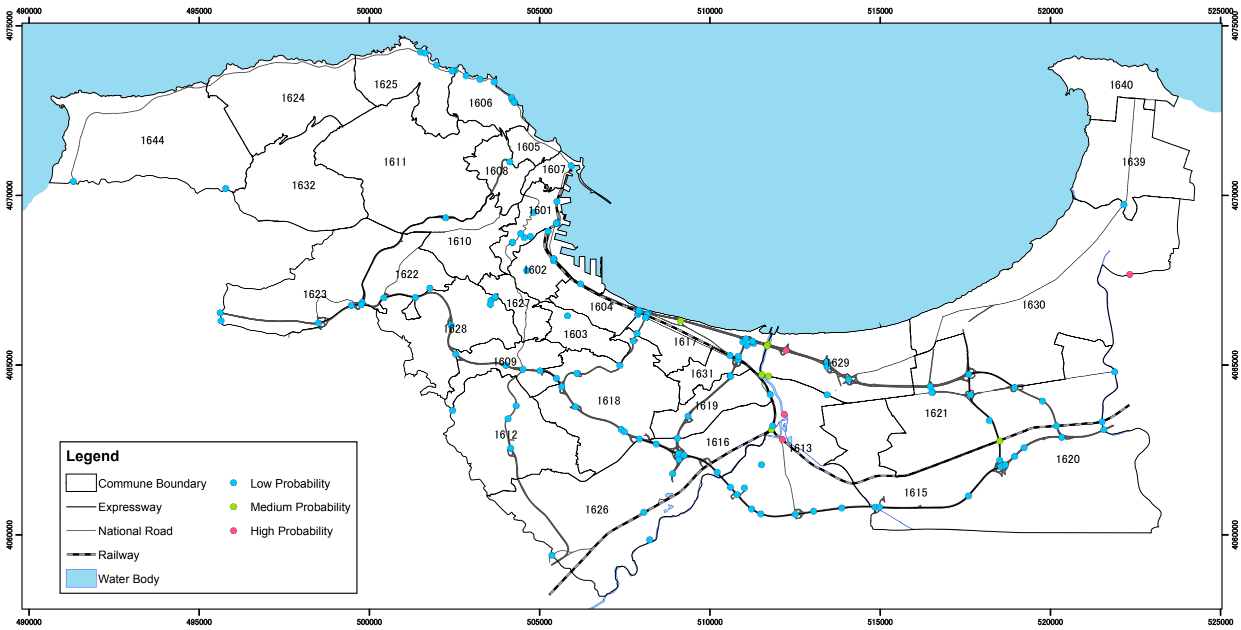


Figure 6-29 Location Map of Probability of Bridges with Falling girders: Zemmouri

(4) Discussion

1) Validation of Results

According to the MTP, bridge characteristics in Algeria are characterized by distinct periods as outlined below:

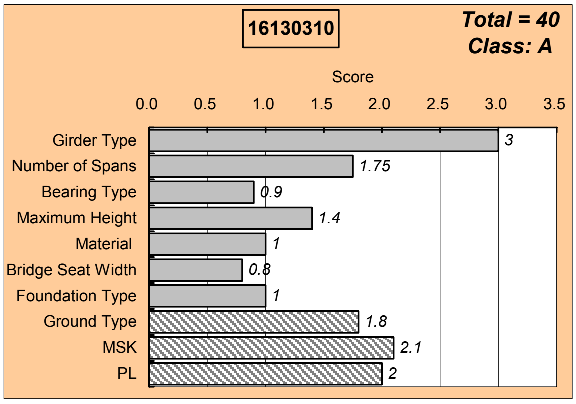
- The colonial period is characterized by the construction of arch masonry and metal bridges, and so on. None of the bridges built during this period were designed considering seismic risk, but they have resisted past earthquakes.
- The period after independence is characterized by an increase in bridge building, but without taking into consideration aseismic calculations.
- The earthquake of El Asnam on 10 October 1980 constituted the main reason for the implementation of bridge aseismic calculations. All buildings constructed after this date have been studied and designed on the basis of the Algerian Aseismic Regulations (RPA 80).
- The first revision of these regulations was undertaken in 1988, a second revision in 1998, and a final revision in 2003. However, the aseismic calculation of works during this period was completed though a verification of the results on the basis of the international regulations (American, Japanese, European codes). During this time interval, the earthquakes that occurred in Algeria were not of great intensity and did not significantly affect the works. It had been considered that the new measures of the RPA in terms of the aseismic calculation of works were sufficient.
- Following the damage caused by the Boumerdes Earthquake on 21 May 2003, a revision of the RPA was necessary. Thus, a new seismic zoning was established. Following this new data, the MTP now undertakes to endow this sector with a specific aseismic regulation for design. After the elaboration of this regulation, the building of bridges will enter a new era.

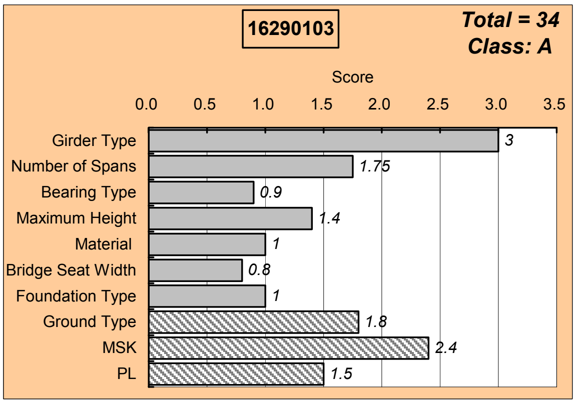
The summarized results of Katayama's method indicate that masonry arch bridges are judged as class "C" (low probability) and the ratio of class "A" (high probability) and "B" (moderate probability) is 14.9 % in case of Khair al Din. These results are broadly consistent with the above mentioned bridge characteristics in Algeria.

2) Features of the Result

Each category score of the bridges judged as class "A" (high probability) and class "B" (moderate probability) is shown in Figure 6-30 (Khair al Din) to Figure 6-31 (Zemmouri).

Generally speaking, in the study area (with the exception of masonry bridges and colonial age bridges) there is a low probability of the girders falling off the bridges, because in most instances enough seat width has been provided for prevention of the girders falling off the bridges . For class "A" and "B" bridges located in high seismicity and / or liquefaction prone areas, lateral movement of the piers / abutments due to liquefaction increases the probability of girders falling off the bridges. Hence, the following bridges should be investigated to judge the necessity of counter measures in case of liquefaction.


16130310
Total = 40
Class: A
Score
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Girder Type 3
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.1
PL 2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Girder Type 3
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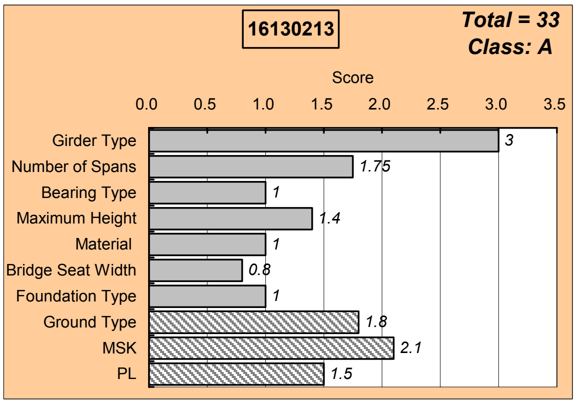
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5


16130213
Total = 33
Class: A
Score
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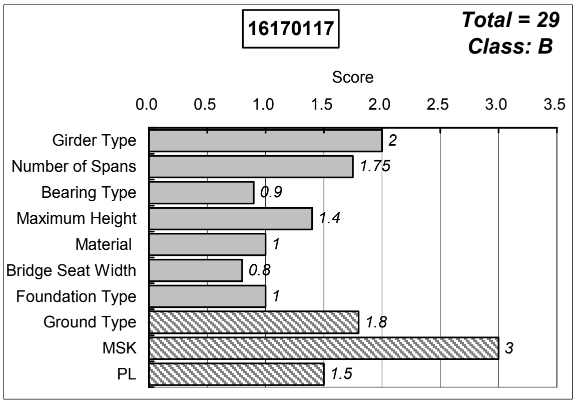
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.1
PL 1.5


16170117
Total = 29
Class: B
Score
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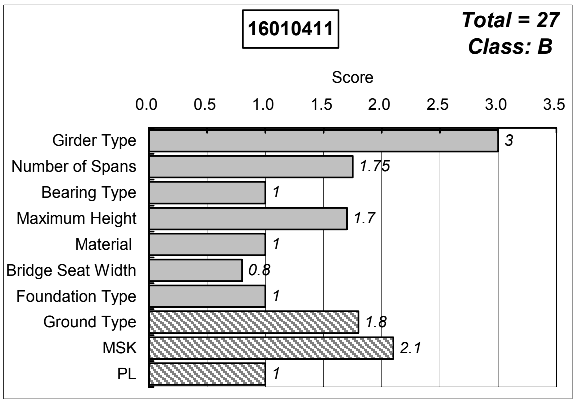
Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 3
PL 1.5


16010411
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Class: B
Score
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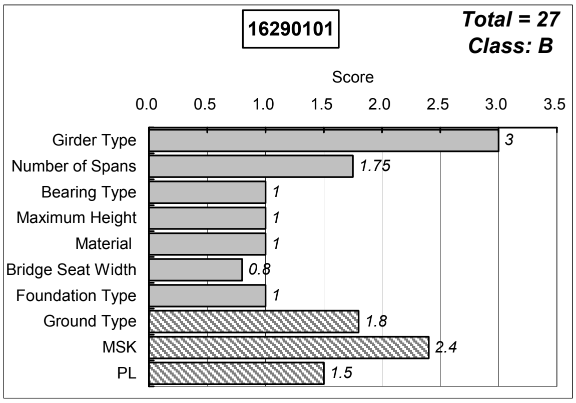
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1.7
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.1
PL 1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Total = 27
Class: B
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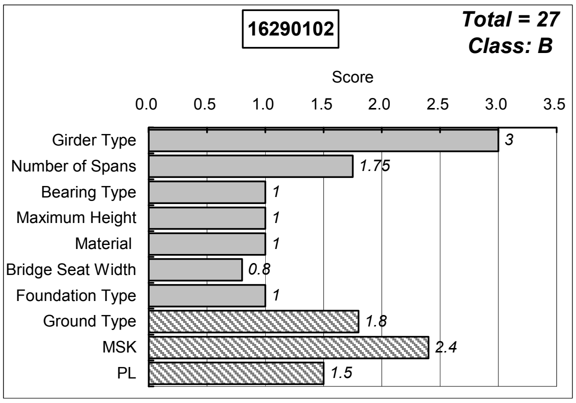
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5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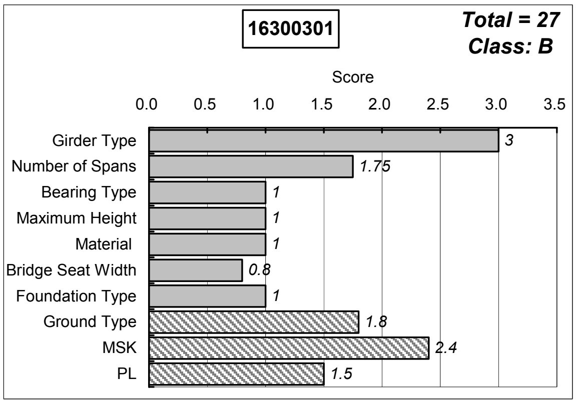
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5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Score
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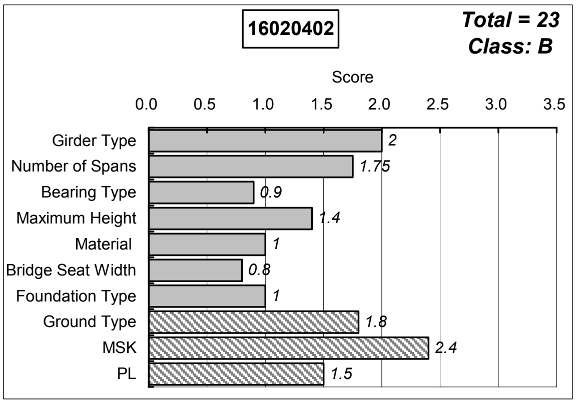
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5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Total = 23
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Score
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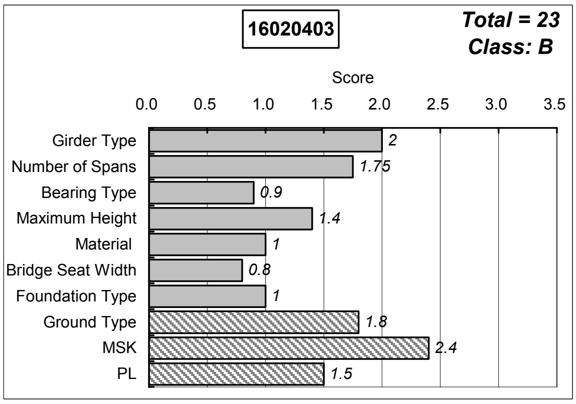
Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5


16020403
Total = 23
Class: B
Score
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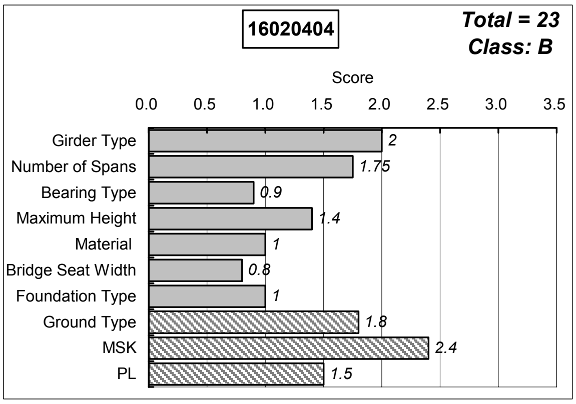
Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5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Total = 23
Class: B
Score
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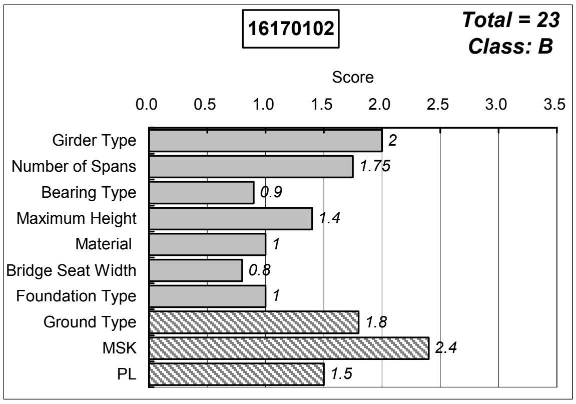
Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5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Total = 23
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Score
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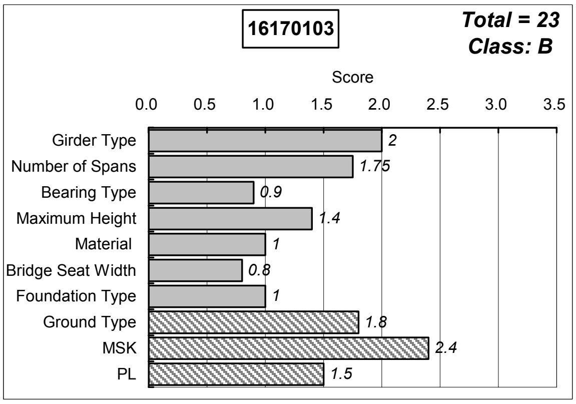
Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5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Total = 23
Class: B
Score
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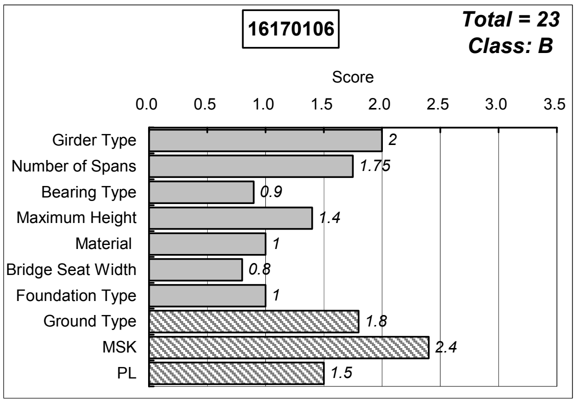
Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5


16170106
Total = 23
Class: B
Score
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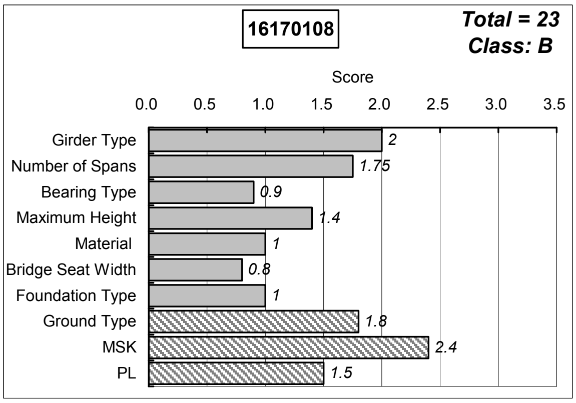
Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5


16170108
Total = 23
Class: B
Score
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Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5

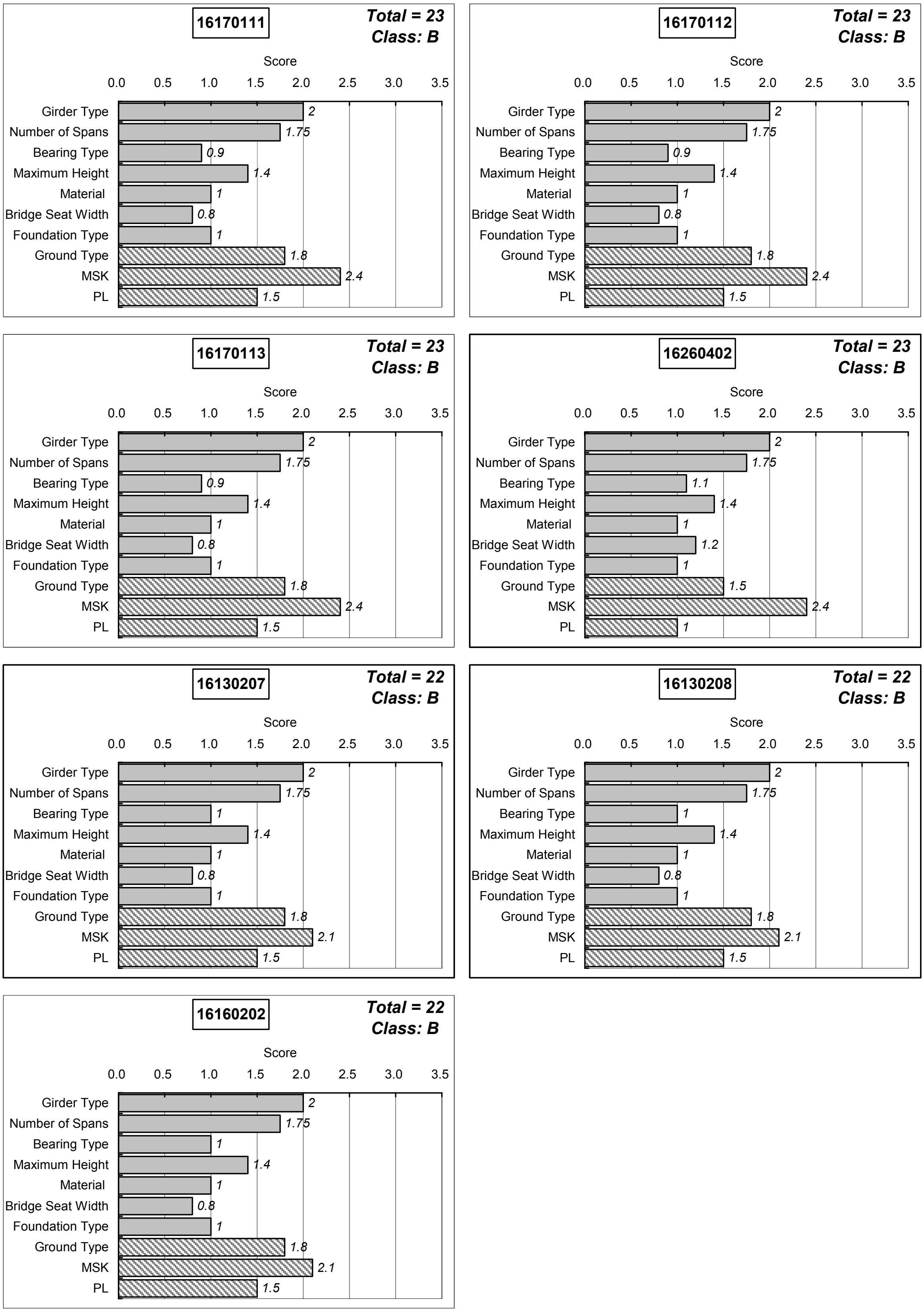
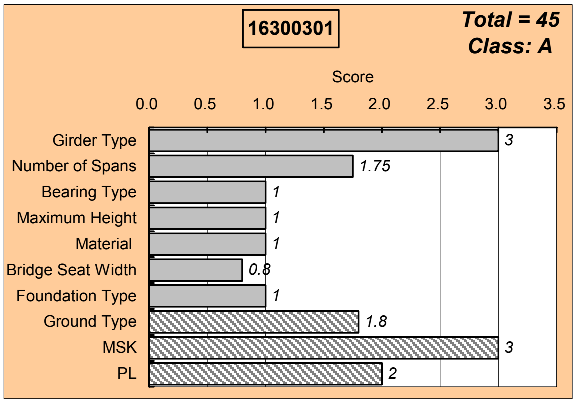


Figure 6-30 High and Moderate Probability of Girders Falling off of Bridges: Khair al Din


16300301
Total = 45
Class: A
Score
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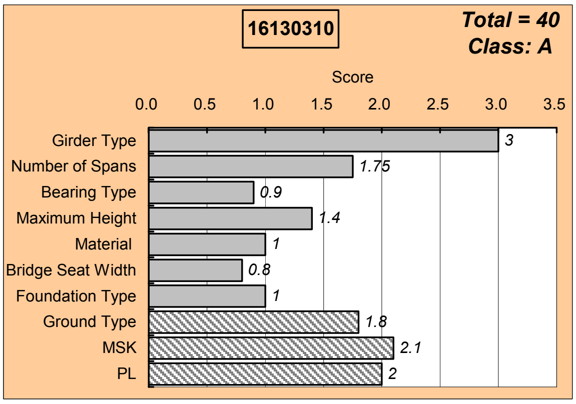
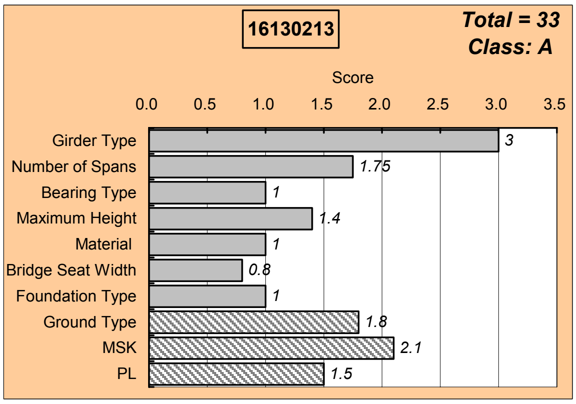
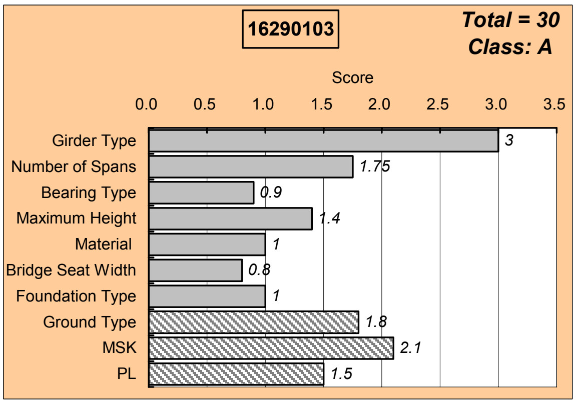
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 3
PL 2


16130310
Total = 40
Class: A
Score
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Girder Type 3
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.1
PL 2


16130213
Total = 33
Class: A
Score
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.1
PL 1.5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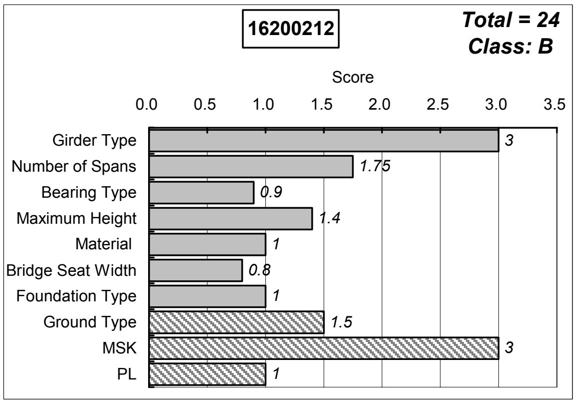
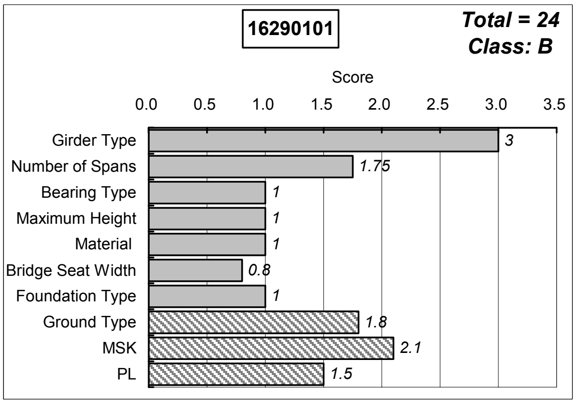
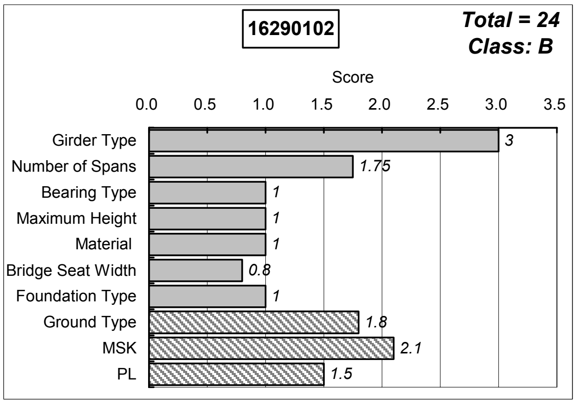
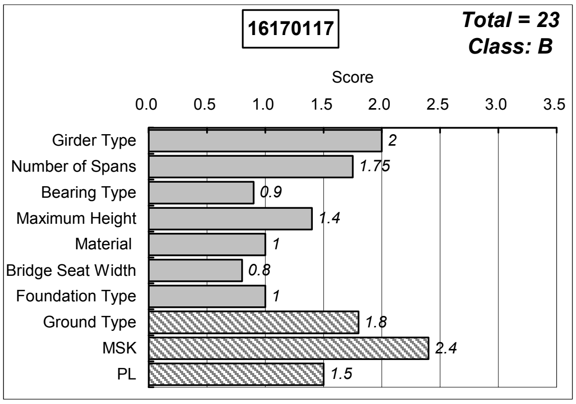
Girder Type 3
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.1
PL 1.5


16200212
Total = 24
Class: B
Score
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Girder Type 3
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.5
MSK 3
PL 1


16290101
Total = 24
Class: B
Score
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.1
PL 1.5


16290102
Total = 24
Class: B
Score
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Girder Type 3
Number of Spans 1.75
Bearing Type 1
Maximum Height 1
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.1
PL 1.5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Score
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Girder Type 2
Number of Spans 1.75
Bearing Type 0.9
Maximum Height 1.4
Material 1
Bridge Seat Width 0.8
Foundation Type 1
Ground Type 1.8
MSK 2.4
PL 1.5

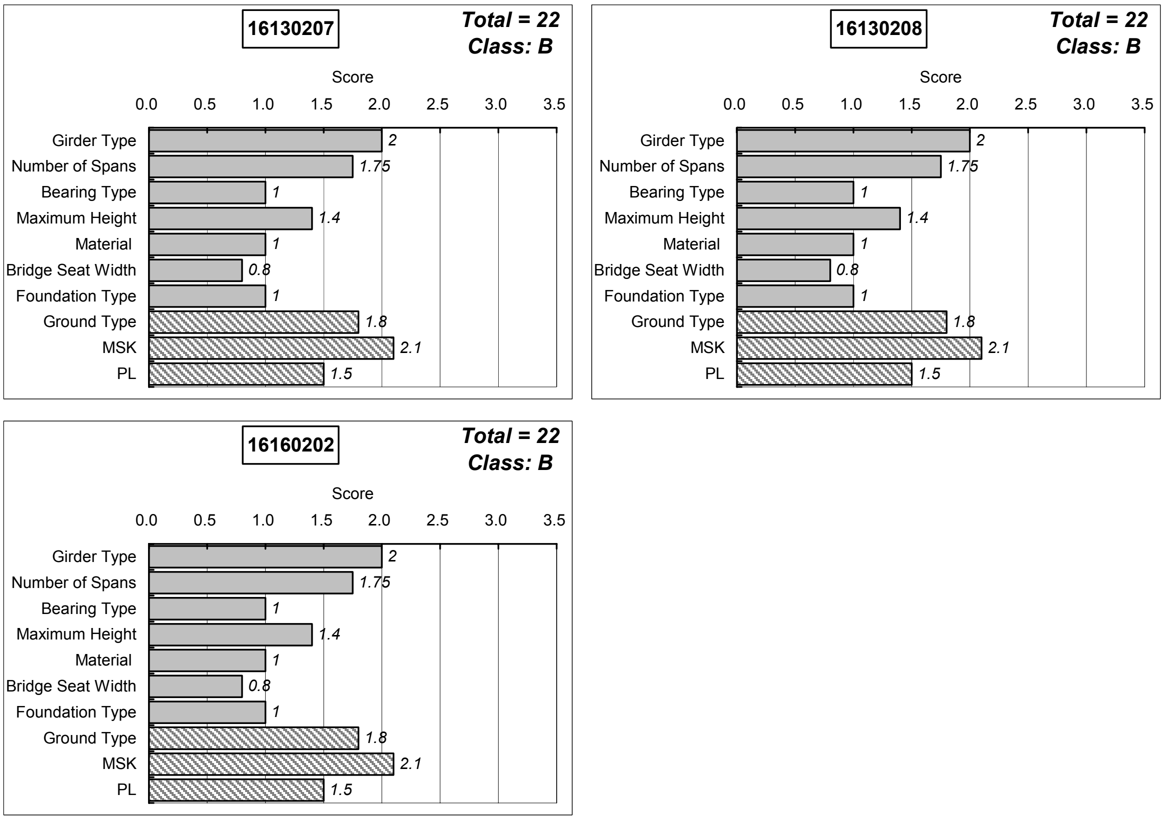

Figure 6-31 High and Moderate Probability of Girders Falling off of Bridges: Zemmouri

6-3-2 Ports

A port is quite important to accept relief aid / goods and rescue support from abroad. Hence, the destruction of the port should be prevented as much as possible.

Most damage to ports and harbors due to past earthquakes was caused by liquefaction. In many cases, piers sank or were tilted and cargo-handling machinery was damaged.

(1) Damage Function

Port damage for the scenario earthquake was estimated qualitatively. In seismic microzonation studies in Japan, a relationship between damage grade and ground motion / liquefaction potential was compiled as shown in Table 6-19, this being based on the past earthquakes including the Kobe Earthquake in 1995.

Table 6-19 Damage to Ports due to Past Earthquakes

	Ground Acceleration (gal)				
	0 to 150	150 to 200	200 to 300	300 to 450	more than 450
Liquefying soil	0	1	2	3	3
Non liquefying soil	0	0	1	2	3

Damage grade 0 : No damage
Damage grade 1 : Slight damage, there are cracks and deformation to sub-structures
Damage grade 2 : Moderate damage, there is deformation to main-structures
Damage grade 3 : Heavy damage, there is heavy deformation to main-structures and function is lost

(2) Verification of Damage Function

In the Boumerdes Earthquake, an aerial inspection of the Algiers Port was conducted by LEM. The damages were assessed as follows:

[Container Terminal]

- Gaps in the mortar between the blocks
- Crack along the entire length of the quay, the width sometimes reaching 10 cm
- Compaction of infill causing voids beneath the pavement,
- Compacting of more 10 cm compared to the quay coast (rib)
- Presence of cavities under a major part of the crane rails due to the compaction of the underlying fill.
- Presence of 4 open cavities at the pier of El Hadja
- Other cavities and slump (sag) were noted near the container terminal access ways

[Other Quays]

Regarding the information provided by the Departments of the DTP and EPEAL, the affected zones were located to the east of the pier Oued Hamimine. The quay in the west was not damaged, according to those same sources.

- Degradation of the concrete and breaks in the seals of the prefabricated oil storage tanks
- Break and moving of part of the Duc d' Albe
- Cracks along the quay (cracks 1 to 4 cm wide with a depth sometimes reaching 1 m)
- Break in the pavement along the quay due to 5 cm of compaction of the substrata
- Offset between the curbing and earth platform
- Delamination of the tiles covering the gutter stones
- Ruptures and compacting between the earth platform and curbing in some areas reaching 2 cm
- Breaks and compacting of the finger pier curbing.

The above mentioned damage is judged as damage grade 1 (slight damage) to 2 (moderate damage) under the occurrence of liquefaction. And the peak ground acceleration near the Algiers Port was around 265 gal according to information from the counterpart. These pieces of information / data are plotted as shown in Figure 6-32.

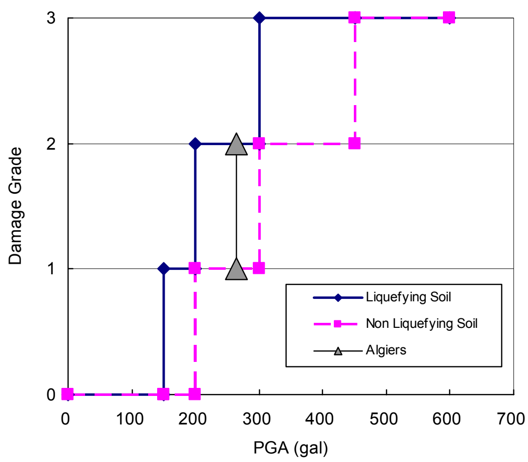

Figure 6-32 Verification of the Damage Function for the Port

As the above figure shows, damage at the Algiers Port due to the Boumerdes Earthquake and the damage function have a good correlation. Hence, the damage function was applied for the port damage estimation in this Study.

(3) Result and Discussion

Figure 6-33 shows the result of the port damage estimation. Here, the liquefying soil is defined as having a liquefaction potential ($0 \leq P_L$) on the safe side.

In a case similar to Khair al Din, the north part of the port will suffer moderate damage and other parts may cease to function. In a case similar to Zemmouri, the north part of the port will continue to function, however, other parts, especially the berth area, will suffer heavy damage and may also cease to function.

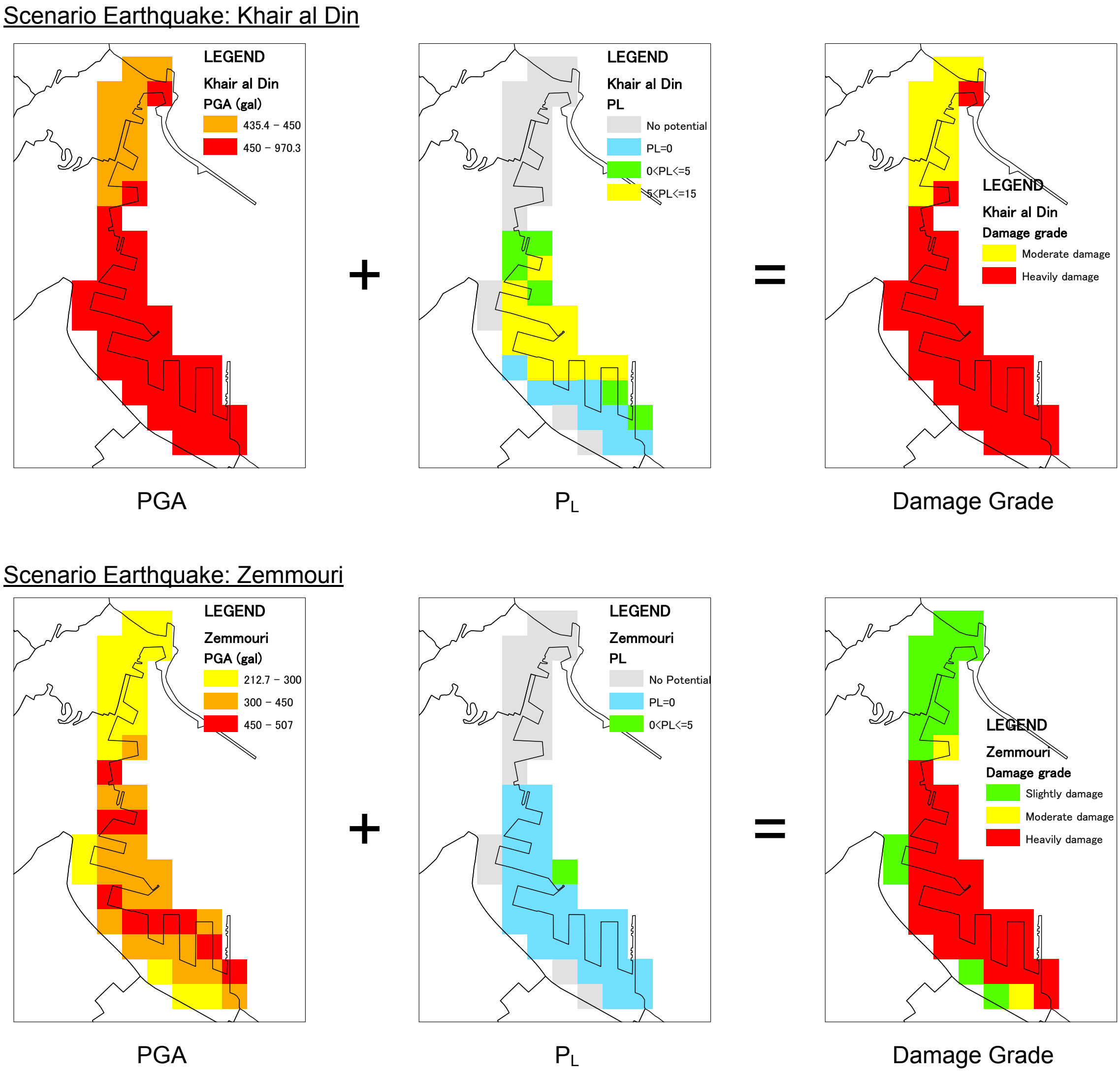

Figure 6-33 Result of Port Damage Estimation