1.7.4 Land Use

(1) Macroscopic View on Previous Studies

Agricultural land is predominant in the Kathmandu Valley followed by forests and grasslands. Over the past decades the urban built-up area has sprawled across agricultural land and recently on more fertile agricultural land along the river flood plains closer to the developed urbanising areas of the five Municipalities.

Urbanisation has also encroached into adjoining village districts converting agricultural land to urban use. Agricultural lands in the Kathmandu Valley have reduced from approximately 42,000 ha. in 1984, to 33,300 ha. in 1994, and 27,600 ha. in 2000, i.e., a decrease of nearly 600 ha. to 1,000 ha. / year as shown in the Table 1.7.3.

Table 1.7.3 Land Use in the Kathmandu Valley

Land Use	1984 *1)		1994 *1)		2000 *2)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Urban	2,096	4.8	8,378	13.1	9,193 *3)	13.8
Agriculture	40,950	64.0	33,308	52.1	27,570	41.4
Forest/Grassland	19,439	30.4	20,945	32.7	20,677	31.0
River	479	0.8	583	0.9	496	0.7
Others (airport/pond, etc.)	NA	-	336	0.5	310 *4)	0.5
Abandoned land	NA	-	414	0.7	NA	-
Rural Settlement *3)	NA	-	NA	-	8,404	12.6
Total	63,964	100	63,964		66,655	100

1) Source: Regulating Growth: Kathmandu Valley IUCN 1995
2) Source: Draft Development Plan 2020 for Kathmandu Valley; KVTDC, 2000
3) Includes 2,593 ha of new residential development in VDCs which are mainly urban sprawl
4) Covers transportation only
5) Consists predominantly of traditional village settlements
6) Source: City Development Strategy; W.B./KMC 2001

Urban land had increased correspondingly from about 3,100 ha. in 1984, to 8,400 ha. in 1994, and 9,200 ha. in 2000: i.e. 130 ha. ~ 530 to 380 ha./year average over these terms. Because of differences in the calculation of the total area of the Valley, the increase in the percentage of urban land between 1994 and 2000 does not appear very significant. However, there has been a real increase in urban land use by about 820 ha. during the 6 year period (Ave. 137 ha. / year simply). It had been estimated that the net area under urban development would be about 10,100 ha. in 2010, and 14,300 ha. in 2015. Considering the fact that the study quite significantly underestimated the future population of the Valley, it could be assumed that the estimated urban land use during the projected periods would also be much higher *[1]. The Development Plan 2020 (KVTDC) had estimated that if

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[1] Halcrow; KMV Urban Development Plans and Programs; 1991

a gross density of 300 persons per hectare (as recommended) could be achieved within the existing urban areas, the demand for urban land in the next 20 years would be slightly over 3,600 ha. However, considering the current trend of owner occupied single housing, such demand for urban land will probably be much higher than estimated *[2].

(2) Land Uses in Kathmandu Metropolitan City

A study undertaken by MSUD *[3] in 1989 determined that only 62% of Kathmandu municipal area and 52% of Lalitpur municipal area had been built up. Quite a significant proportion of open land existed within the city, comprised of pockets of undeveloped land restricted from being developed due to lack of access. This can be summarised that urban expansion had already been occurring in the peripheral areas where underdeveloped land was available closer to the city centre.

(3) Land Use in Terms of Urban Planning Issues and Implications

The current trend of mixed land use is preferred to segregation of different uses. The mixed land use is expected to have number of advantages: enhanced neighbourhood vitality, increased accessibility, etc.*[4] However, incompatible land uses such as labour-intensive polluting activities e.g., which threaten the basic harmony of neighbourhood, are discouraged close to the residential area. Such activities should be encouraged in urban peripheral locations or appropriately outside the Valley. Impact assessments of these activities should be required to identify ways to mitigate the impacts or suggest alternatives. They are usually encouraged in highly accessible locations such as beside ring roads. A summary of issues on urban land use in KMC is as follows:*[5]

a) Low density urban sprawl with pockets of inaccessible land within city…/ High infrastructure cost and inefficient use of land…/ Lack of access to the parts of city areas.
b) Lack of urban space within existing municipality area required development purposes …/ Inability to make future expansion plans …/ Deficiency in urban services.
c) Inadequate zoning regulations and weak monitoring of development

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[2] KMC / World Bank; City Diagnostic Report; 2001

[3] Management Support for Urban Development

[4] KVTDC; Development Plan 2020; July 2000. (6.4.2.1)

[5] KMC / World Bank; City Diagnostic Report; 2001

activities…/ Incompatible land uses…/ Violation of bylaws…/ No control on location of industries.

d) Lack of people's participation in the planning process…/ Lack of acceptance and support for city development activities.

e) Lack of open spaces …/ Open recreational spaces for the underprivileged public…/ Absence of safety areas during times of seismic activities especially.

f) Lack of clearly defined river domain…/ Encroachment on river domain by squatters and waste disposal.

g) Violation of building by-laws…/ Encroachment on public land, Inadequate access, Unsafe and unauthorised buildings.

Table 1.7.4 Kathmandu Metropolitan City Land Use in 1995

	Land Use	Area (ha)	%
1/	Mixed residential/commercial	3273.6	64.5
2/	Commercial/industrial	82.6	1.6
3/	Institutional	239.2	4.7
4/	Transport (airport/bus terminal)	166.3	3.3
5/	Others (vacant/open land, vip area, squatter)	1314.3	25.9
	Total	5076.0	100.0

Source: Cities Data Book 2000: extracted from City Development Strategy (W.B./KMC)2000

1.8 Damage to Buildings

1.8.1 Inventory

A Building Inventory was carried out by the Study Team to clarify the nature, distribution and strength of buildings in the Kathmandu Valley. The distribution of each type of building was also clarified to assess likely damage due to earthquakes. The procedure of the inventory was: inventory of over 1,000 sample buildings; onsite observation; and data analysis for hazard assessment and mitigation planning.

(1) Number of Buildings in the Kathmandu Valley

There was no statistic data on the number of buildings. The number of buildings was assumed to be the same as the number of households projected on the basis of census data in 1981 and 1991.

(2) Interview

A questionnaire was filled out by a local engineer consisting of 100 questions about owners, residential buildings, location, structure, age, sketch, repair, extension, number of stories, shape, usage, layout, soil, topography, cracks, etc.

A stratified multi-stage sampling method was applied for the selection of the 1,000 samples, which is about 0.4 % of total buildings in the Valley.

Stratification was based on the following factors.

- Locality: urban, sub-urban and rural, and urban planning
- Land use: commercial, industrial, and residential
- Topography, geology, and geomorphology

The numbers of buildings and samples are shown in Table 1.8.1.

Table 1.8.1 Number of Samples according to Locality Classification

Locality classification	Number of households [X] (= Number of buildings)	Number of samples	
		Calculated (0.004X)	Actual
Urban	163,435	654	690
Sub-urban	37,107	148	180
Rural	55,661	223	260
Total	256,203	1,025	1,130

The results of the survey are summarised below.

a) Building type

Main types of building in the Valley are as follows:

- Stone with mud mortar (ST)
  Buildings in rural areas are mainly of stone, as shown in these photos. Two shapes of stone are used; round riverbed rocks and squared dressed stones.
- Adobe (AD)
  This is an old type of building composed of sun-dried bricks with mud mortar. There are many adobe houses in rural areas. Adobe houses also exist in the old urban or sub-urban areas, mainly on elevated ground.

Photo 1.8.1 Stone with mud mortar (ST)

Photo 1.8.2 Adobe (AD)

- Brick with mud mortar (BM)
  It can be seen that floors and roofs are timber structures. There is also a certain number of examples using sun-dried brick inside covered by fired brick on the exterior.
- Brick with cement mortar(BC)
  A distinctive feature is the lack of or insufficient number of RC columns. The

use of CS (cement sand) was adopted only 30 years ago, so its history here is short. A destructive earthquake has not yet been experienced, except for the 1988 earthquake, and evaluation of the strength of these buildings is needed.

- Reinforced Concrete frame with masonry (RC)

  enerally, 50% of the households are cement-bonded types. Over 90% of new RC frame buildings are typical RC frame with masonry structures.

Photo 1.8.3
Brick with mud mortar (BM)

Photo 1.8.4
Brick with cement mortar (BC)

Photo 1.8.5
Reinforced concrete frame with masonry (RC)

Table 1.8.2 shows the percentage of each type of building in the Kathmandu Valley.

Table 1.8.2 Percentage of Buildings by Type

ST	AD	BM		BC	RC		Total
		BM Regular	BM Well		Story <= 3	Story >= 4	
4.7	18.7	27.2		26.0	23.4		100.0
		25.4	1.8		19.3	4.1	

b) Building classification of the Kathmandu Valley

The distribution of building types was mapped by visual observation supplemented with building inventory survey data, topographic maps and aerial photographs. The results are classification maps showing predominant building type in each 500 m by 500 m grid cell in Figure 1.8.1.

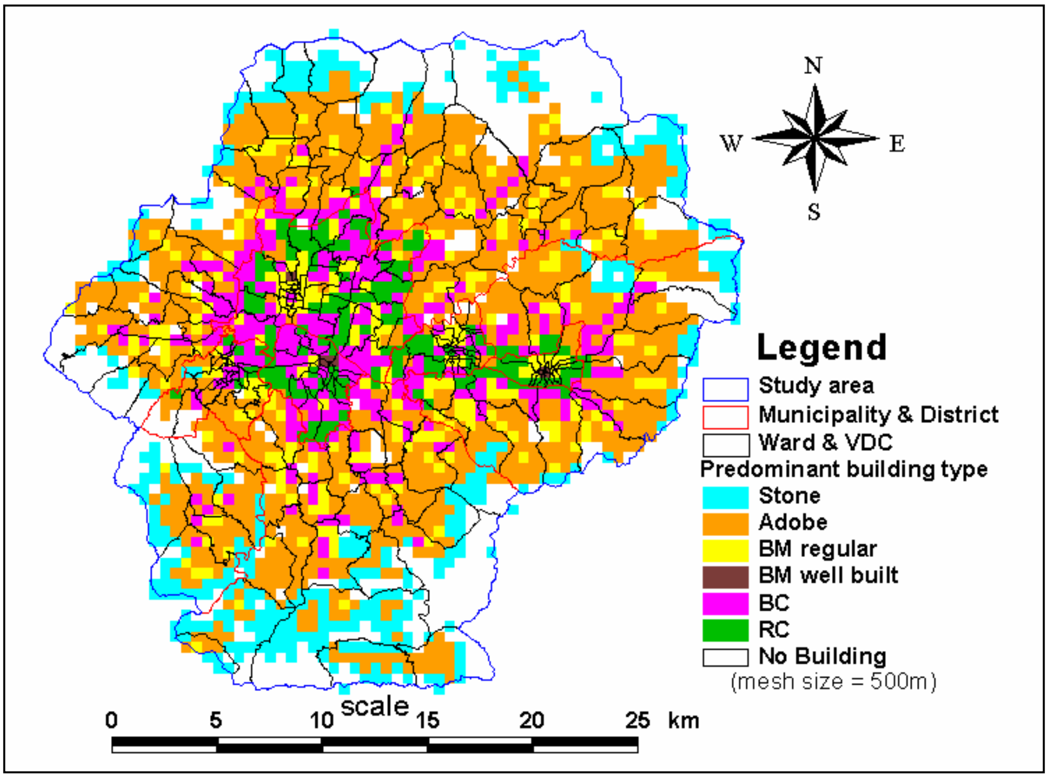
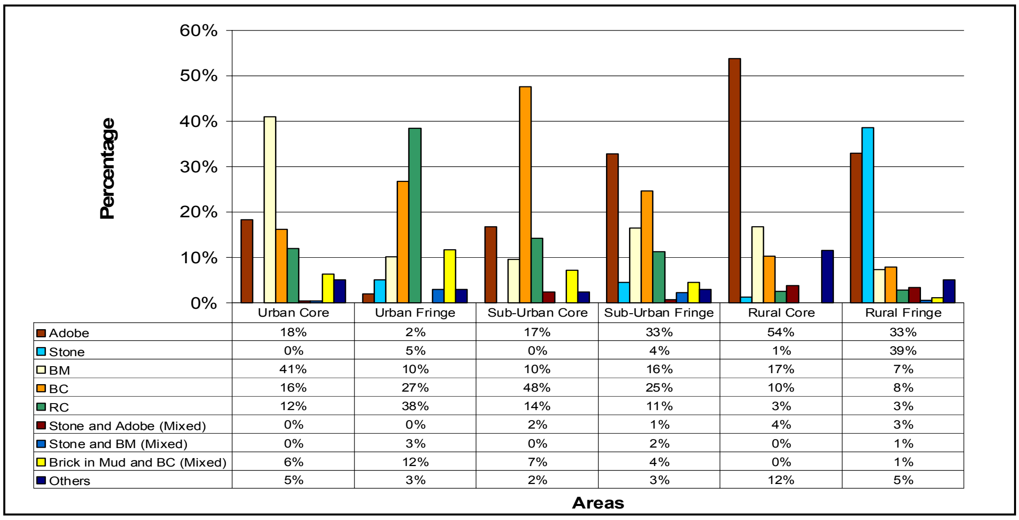


Figure 1.8.1 Classification Map showing Predominant Building Type

c) Frequency of Building Types in Each Locality

Frequency of building types in each locality is shown in Figure 1.8.2.

- Based on the materials of buildings, buildings in the Kathmandu Valley were classified into five types (Stone: ST, Adobe: AD, Brick with Mud Mortar: BM, Brick with Cement or Lime Mortar: BC, Reinforced Concrete Frame with Masonry: RC).
- In the urban areas, the major building types are brick masonry structures with mud or cement and reinforced concrete frames. The proportion of buildings with a reinforced concrete frame structure is higher in urban fringe than in urban core. The proportion of adobe is also high, especially in the urban core where old buildings are dominant.
- In the rapidly growing suburban areas, brick masonry with cement mortar is dominant in the core, as well as the fringe areas. Brick masonry with mud and adobe building types are common in the suburban area. The proportion of reinforced concrete buildings is relatively low, 14% in the suburban core and 11 % in the suburban fringe.
- In the rural areas, the major types are adobe and stone/brick masonry in mud mortar, while brick masonry with cement or reinforced cement structures are significantly low in proportion.



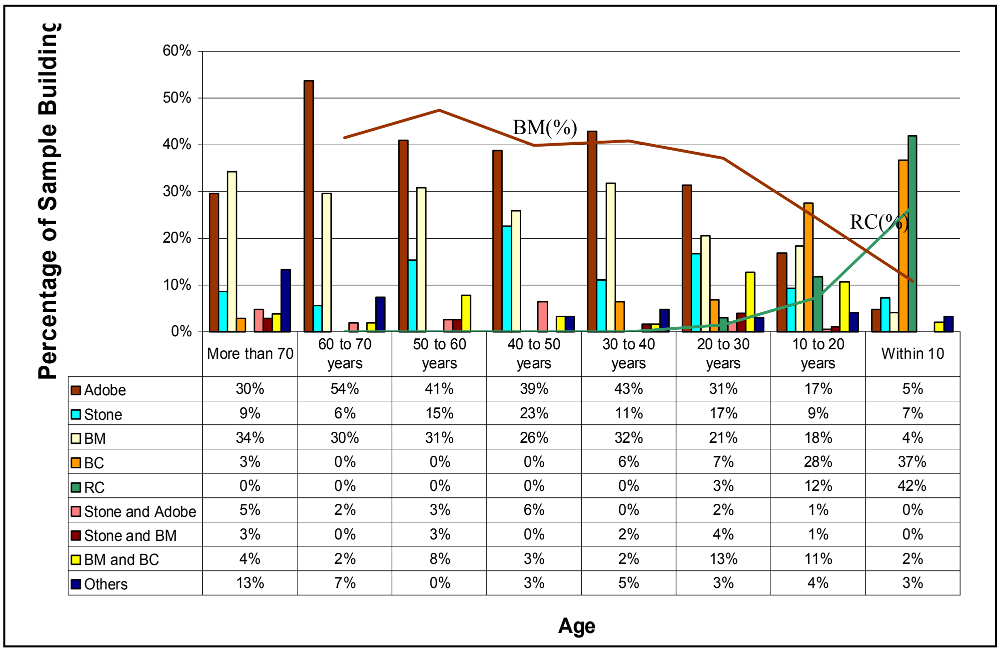
	Urban Core	Urban Fringe	Sub-Urban Core	Sub-Urban Fringe	Rural Core	Rural Fringe
Adobe	18%	2%	17%	33%	54%	33%
Stone	0%	5%	0%	4%	1%	39%
BM	41%	10%	10%	16%	17%	7%
BC	16%	27%	48%	25%	10%	8%
RC	12%	38%	14%	11%	3%	3%
Stone and Adobe (Mixed)	0%	0%	2%	1%	4%	3%
Stone and BM (Mixed)	0%	3%	0%	2%	0%	1%
Brick in Mud and BC (Mixed)	6%	12%	7%	4%	0%	1%
Others	5%	3%	2%	3%	12%	5%

Figure 1.8.2 Frequency of Building Types in Each Locality

d) Building type by age

The proportion of building types by age of 10-year age intervals is shown in Figure 1.8.3.

- Adobe and BM were main types of building until 30 years ago.
- Construction of RC started 20 to 30 years ago, and increased since 10 to 20 years ago.
- In recent 10 years, BC and RC are the dominant types of buildings.
- About 23% of the total buildings are more than 50 years old, indicating high vulnerability.



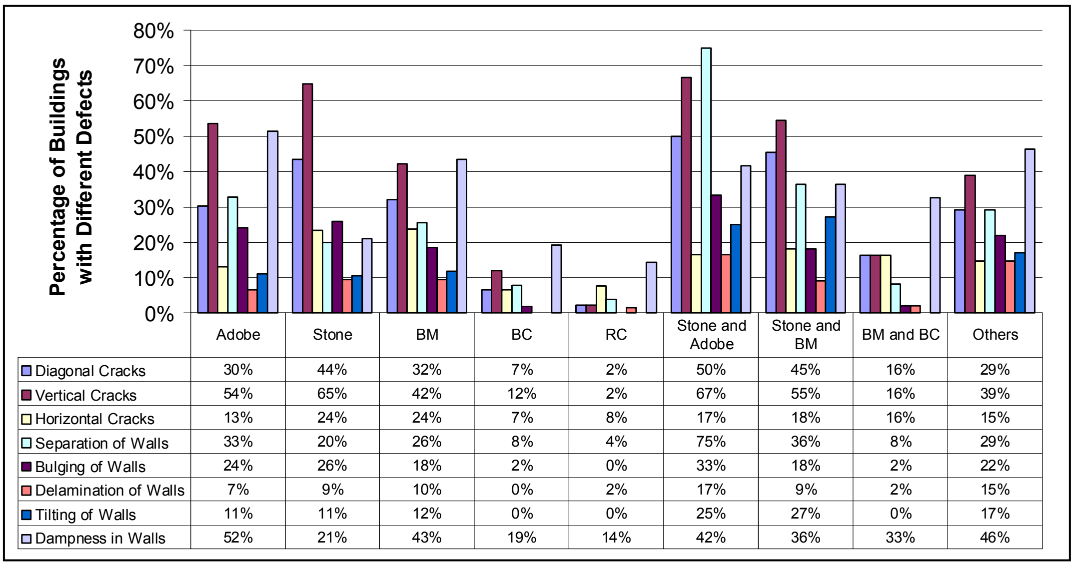
	More than 70	60 to 70 years	50 to 60 years	40 to 50 years	30 to 40 years	20 to 30 years	10 to 20 years	Within 10
Adobe	30%	54%	41%	39%	43%	31%	17%	5%
Stone	9%	6%	15%	23%	11%	17%	9%	7%
BM	34%	30%	31%	26%	32%	21%	18%	4%
BC	3%	0%	0%	0%	6%	7%	28%	37%
RC	0%	0%	0%	0%	0%	3%	12%	42%
Stone and Adobe	5%	2%	3%	6%	0%	2%	1%	0%
Stone and BM	3%	0%	3%	0%	2%	4%	1%	0%
BM and BC	4%	2%	8%	3%	2%	13%	11%	2%
Others	13%	7%	0%	3%	5%	3%	4%	3%

Figure 1.8.3 Building Type by Age

e) Damage of buildings

The survey result for damage to walls in each type of building is shown in Figure 1.8.4.

- Many visible defects such as cracks, wall separation, bulging, and tilting of walls were observed in mud-based buildings (adobe, and brick or stone masonry in mud mortar).
- On the contrary, much fewer visible defects were seen in cement-based constructions such as brick-in-cement and RC frames.
- Vertical cracks had developed in about 12% of the surveyed brick masonry buildings with cement mortar, diagonal and horizontal cracks were seen in 7% of the buildings, and separation of walls in about 8%.
- The major problem seen in RC construction (in about 8% of the buildings) was the development of horizontal cracks, mostly along the wall-beam contacts.
- Dampness is a serious problem in all buildings.



	Adobe	Stone	BM	BC	RC	Stone and Adobe	Stone and BM	BM and BC	Others
▨ Diagonal Cracks	30%	44%	32%	7%	2%	50%	45%	16%	29%
■ Vertical Cracks	54%	65%	42%	12%	2%	67%	55%	16%	39%
□ Horizontal Cracks	13%	24%	24%	7%	8%	17%	18%	16%	15%
□ Separation of Walls	33%	20%	26%	8%	4%	75%	36%	8%	29%
■ Bulging of Walls	24%	26%	18%	2%	0%	33%	18%	2%	22%
■ Delamination of Walls	7%	9%	10%	0%	2%	17%	9%	2%	15%
■ Tilting of Walls	11%	11%	12%	0%	0%	25%	27%	0%	17%
□ Dampness in Walls	52%	21%	43%	19%	14%	42%	36%	33%	46%

Figure 1.8.4 Damage to Wall in Each Type of Building

1.8.2 Preparation of Fragility Curves

Damage to buildings causes not only the loss of property but is also hazardous to human life. The grade of damage depends on the intensity of earthquake motion and the strength of the buildings. Because the strength of buildings has a close relation to the type of the buildings, classification of the type of buildings is done in this study as the first step for the estimation of damage to buildings.

Based on reports from Nepal and India, as well as field observation, buildings in the Kathmandu valley were classified into the following seven types.

- Stone(ST)
- Adobe(AD)
- Brick with Mud Mortar, type-1: Poorly built (BM)
- Brick with Mud Mortar, type-2: Well built (BMW)
- Brick with Cement or Lime Mortar(BC)
- Reinforced Concrete Frame with Masonry(RC) of 4 stories or more (RC5)
- Reinforced Concrete Frame with Masonry(RC) of 3 stories or less (RC3)

As the second step, the relation between the damage ratio and ground acceleration is determined for each type of building. A graph showing the above-mentioned relation is called "Fragility Curve". In this study, fragility curves for the buildings in the Kathmandu Valley were prepared by calibrating an existing fragility curve for Indian buildings prepared by Arya and an existing curve of West Nepal prepared by a UNDP study. For the calibration, the damage of the 1988 earthquake recorded in the UNDP report was analysed as shown in Table 1.8.3.

Table 1.8.3 Analytical Result of Damage to Buildings by the 1988.8.20 Earthquake

MMI in Hilly Region	Acceleration (gal)	Damage rate (%)	Totally collapse rate (%)
6.67	103.5	27.4	15.3
6.33	81.8	15.6	7.5
6.00	65.2	10.6	3.8
5.67	51.9	6.8	3.7
5.33	41.0		
5.00	32.7	1.6	0.9
4.50	23.1	2.5	1.8

The analytical result in Table 1.8.3 was plotted on the existing fragility curves in Figure 1.8.5.

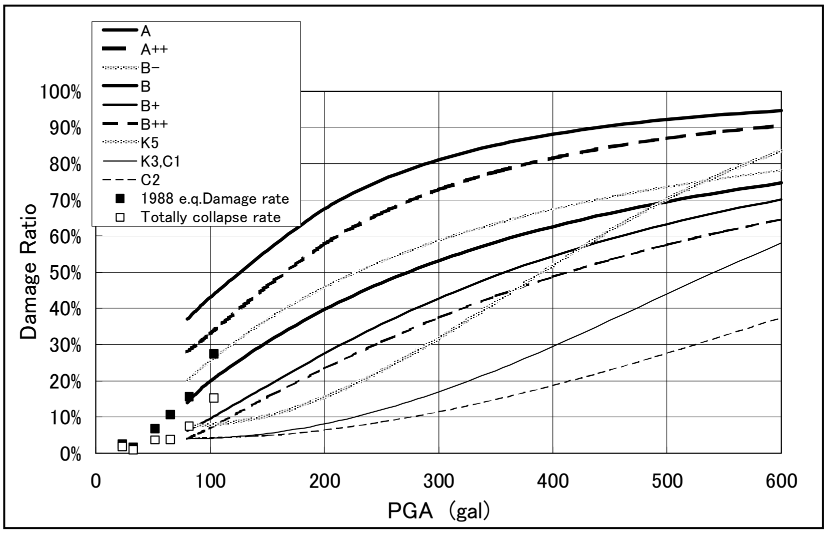


Figure 1.8.5 Existing Fragility Curves for Building Damage

Based on Figure 1.8.5, a fragility curve for each type of building in the Kathmandu Valley was determined as follows:

- Most of buildings damaged by the 1988 earthquake were adobe type (AD) and the envelope of the plotted points of the damage rate by the 1988 earthquake appear to be an extension of the curve A++. Therefore, the fragility curve for the damage rate for AD in the Valley can be a curve connecting the curve A++ and the envelope.
- The envelope of the plotted points of the collapse rate from the 1988 earthquake appears to be an extension of the curve B. Therefore, the fragility curve for the collapse rate of AD in the Valley can be a curve connecting the curve B and the envelope.
- The strength of stone type (ST) seems to be similar to that of AD, and thereby, the fragility curve used for ST will be the same for AD.
- The buildings of RC frame with masonry (RC) mentioned in the UNDP report were probably properly constructed, while most of the buildings of RC in the Valley are not built by skilful masons. The strength of RC in the Valley should be evaluated at a lesser level than that mentioned in UNDP report.
- The strength of brick with mud mortar type (BM), well-built brick with mud mortar type (WMB), and brick with cement (BC) seems to be much higher than that of AD and much lower than that of RC. Fragility curves for BM, WMB, and BC should accordingly intermediate between the curves of AD and RC.
- The strength of BC seems to be similar to that of WMB, and thereby, the fragility curves for the two types will be the same.
- The strength of BM seems to be lower than that of BC, and the fragility curve for BM will be shifted to the AD-curve side.

As a result of the above examination, the relation between existing fragility curves and calibrated fragility curves for this study were determined as shown in Table 1.8.4 and Figure 1.8.6.

Table 1.8.4 Existing and Calibrated Fragility Curves

Type of Buildings	Existing curve		Fragility Curve for this Study	
	Prof. Arya	UNDP	Damage Rate	Collapse Rate
Stone (ST)	A		A++	B
Adobe (AD)	A to A+		A++	B
Brick with mud mortar (BM)	B- to B		B	B++
Well-built brick with mud mortar (BMW)	B+		B++	C1
Brick with cement or lime mortar (BC)	B to C1		B++	C1
RC frame with masonry of 4 stories or more (RC5)	C1	K5	1/2[(K5)+(B++)]	1/4[(K5)+(B++)]
RC frame with masonry of 3 stories or less (RC3)	C2	K3	1/2[(K3)+(B++)]	1/4[(K3)+(B++)]

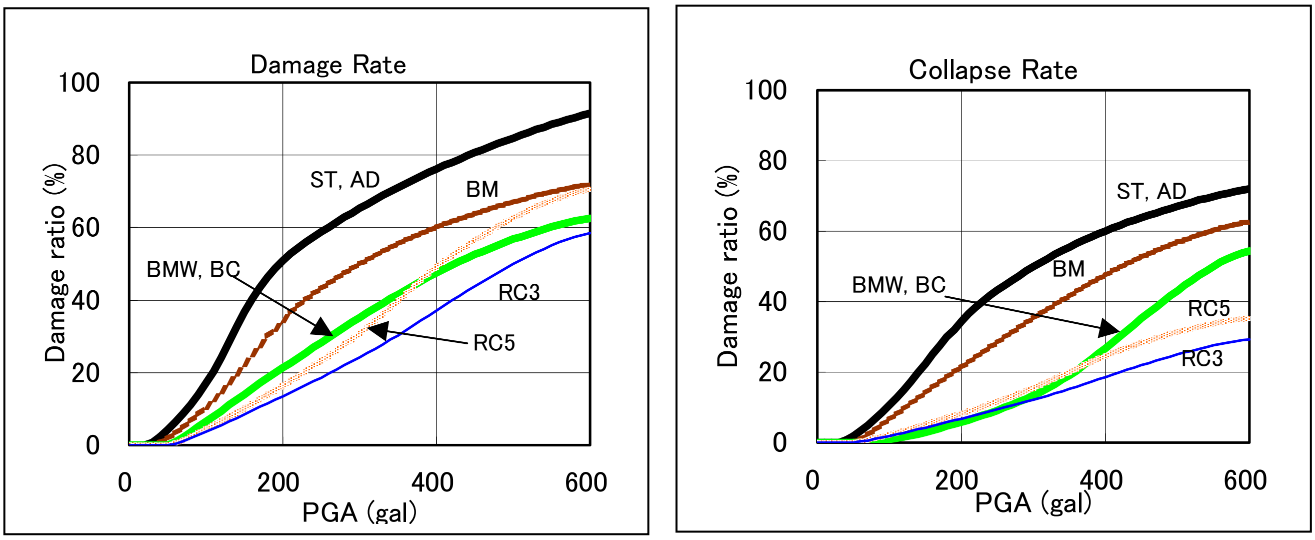


Figure 1.8.6 Fragility Curves Used in the Study

1.8.3 Damage Estimation

The building damages were estimated for four scenario earthquakes; Mid Nepal, North Bagmati, Kathmandu Valley Local and the 1934 Earthquake. In addition to the four scenario earthquakes, another scenario earthquake, that is the 1934 earthquake occurring in the present condition, was prepared in order to show the increase of vulnerability due to recent urbanisation.

Buildings in the Kathmandu Valley can be divided into residential buildings and public buildings such as schools and hospitals. For evacuation and emergency management, the public buildings are rather important and the number of public buildings is rather limited. Damage estimation for the public buildings is accordingly examined separately in the next section. In this section, "Heavily" damaged and "Partly" damaged residential buildings are calculated. Heavily damaged buildings are defined as dangerous and unfit buildings for living, even if roof or walls remain. Partly damaged buildings are available for temporary sheltering and require repair for ordinary living.

The basic factor for the calculation of damage is comparison between the strength of the buildings and seismic vibration only. The other trigger factors such as liquefaction, landslide and fire were not considered in the calculation for the following reasons.

- Liquefaction, landslide, and fire will not occur so much in the Kathmandu Valley, and thereby, these phenomena will not be the main causes of damage to buildings.
- Data on liquefaction, landslide, and fire are not sufficient in terms of the

calculation of damage, while a lot of data on seismic vibration is available.

The outline of the damage estimation criteria is summarised in Table 1.8.5.

Table 1.8.5 Outline of Building Damage Estimation

Object	Residential building
Calculation unit	Each building
Cause of damage	Seismic vibration
Definition of damage	Heavily: Collapsed or un-repairable (unable for living) Partly: Repairable (available for temporary living)

Damage and Collapse rates in the fragility curves of the previous section are based on the figures for reconstruction or repair. Heavily damaged and Partly damaged rates in this section are based on number of buildings. The relation between the categories is accordingly as follows.

- Damage rate = Heavily damaged rate + 1/2 Partly damaged rate
- Collapse rate = Heavily damaged rate

The damages were calculated for each grid cell and structure type. The results are shown in attached Figures 1.8.7 to 1.8.10 and summarised in Table 1.8.6.

Table 1.8.6 Estimated Damage of Residential Buildings

	Heavily	Partly	Total
Mid Nepal Earthquake	53,465 (20.9%)	74,941 (29.2%)	128,406 (50.1%)
North Bagmati Earthquake	14,796 (5.8%)	28,345 (11.1%)	43,141 (16.8%)
KV Local Earthquake	46,596 (18.2%)	68,820 (26.9%)	115,416 (45.0%)
1934 Earthquake in present	58,701 (22.9%)	77,773 (30.4%)	136,474 (53.3%)
1934 Earthquake in 1934	19,395 (36.2%)	16,197 (30.2%)	35,592 (66.3%)

Characteristics of estimated damage for each scenario earthquake are as follows:

a) Mid Nepal Earthquake

The total number of heavily damaged buildings is estimated as 53,000 in the Valley. The heavily damaged ratio is 21%. In total, 50% of buildings are damaged. The number of damaged buildings is large in the core areas of Kathmandu, Lalitpur and Bhaktapur municipalities. The reason for the large number seems to be due to the high density of buildings in these areas. On the other hand, the damage ratio is larger in rural areas than in urban area. The reason for the large ratio seems to be due to the type of buildings, i.e., comparatively stiff RC buildings are dominant in the urban area, while weak Stone or Adobe buildings are dominant in rural areas.

b) North Bagmati Earthquake

The total number of heavily damaged buildings is estimated as 15,000 in the Valley. The heavily damaged ratio is 6%. In total, 17% of buildings are damaged. The number of damaged buildings is large in the Kathmandu municipality core area. The damage ratio in the northern part of the Valley is comparatively high because the seismic intensity is large in the northern area.

c) KV Local Earthquake

The total number of heavily damaged buildings is estimated as 47,000 in the Valley. The heavily damaged ratio is 18%. In total, 45% of buildings are damaged. The number of damaged buildings is large in the core areas of Kathmandu, Lalitpur and Bhaktapur municipalities. The damage ratio of the western part of the Valley is much higher than that of the other area in the Valley because the seismic intensity is higher around earthquake fault model.

d) 1934 Earthquake in present

The total number of heavily damaged buildings is estimated as 59,000 in the Valley. The heavily damaged ratio is 23%. In total, 53% of buildings are damaged. The number of damaged buildings is almost same as that of Mid Nepal earthquake. The damage ratio of the eastern part of the Valley is relatively high because the earthquake fault model is located in the east of the Valley.

e) 1934 Earthquake in 1934

The total number of heavily damaged buildings is estimated as 19,000 in the Valley. The heavily damaged ratio is 36%. In total, 66% of buildings are damaged. The number of damaged buildings is relatively large in the central area of Kathmandu, Lalitpur and Bhaktapur municipalities. The damage ratio in the eastern part of the Valley is very high because of the same reason mentioned above. Further, the damage ratio of the Valley is the highest in these scenarios. It corresponds with the distribution of weak building types such as Stone, Adobe and Brick with mud mortar in 1934.

1.9 Damage to Major Public Facilities

Building damages for following major public facilities were estimated:

- School.
- Hospital.
- Fire station.

A database was set up with regard to the location, structure of the building, year constructed, and the number of stories. The method of damage estimation is the same as that for residential building damage estimation. The number of heavily damaged or partly damaged buildings is calculated by applying fragility curves for earthquake motions to each type of building structure. This method is a statistical one, hence the individual structure of each building, for example wall ratio or plan view, are not taken into account for this damage estimation. It means that the average properties of the building structure, based on its structure type, are counted in the damage estimation.

1.9.1 Schools

There are 2,497 schools in the Kathmandu Valley, 689 of them are public and 1808 are private schools as shown in Table 1.9.1. Public schools provide 10 years education from primary to secondary, and there are 4 types; primary, lower secondary, secondary and higher secondary.

Table 1.9.1 Number of Public Schools in the Kathmandu Valley

Public School										
District / Type	Kathmandu			Lalitpur			Bhaktapur			Total
	Muni.	VDC	Total	Muni.	VDC	Total	Muni	VDC	Total	
PS	35	87	122	21	114	135	23	55	78	335
LS	18	29	47	5	28	33	11	21	32	112
SS	60	55	115	44	26	70	16	11	27	212
HS	12	10	22	2	4	6	2	0	2	30
Total	125	181	306	72	172	244	52	87	139	689
Private School										
District	Kathmandu			Lalitpur			Bhaktapur			Total
Type	Muni.	VDC	Total	Muni.	VDC	Total	Muni	VDC	Total	
PP	438	134	572	8	9	17	16	13	29	618
PS	223	72	295	25	50	75	45	17	62	432
LS	47	23	70	15	23	38	6	14	20	128
SS	253	75	328	45	76	121	37	14	51	500
HS	89	8	97	27	2	29	4	0	4	130
Total	1,050	312	1,362	120	160	280	108	58	166	1,808

In this study, only 347 public schools (almost half of total number) could be inventoried as shown in Table 1.9.2 and the location map of these public schools is in Figure 1.9.1. Based on this inventory, the characteristics of public schools are summarised below.

- In terms of the number of schools, there is no big deviation in each municipality or VDC.
- The number of buildings in each school is mainly 1 or 2.
- Most of the buildings are one or two storied and built within the past 30 years.
- The area of buildings is from 20 to 500 square meters, but most of them are less than 100.
- Concerning structural type, brick with mud mortar is common, adobe or brick with cement mortar is a little less, and stone and reinforced concrete are rare.

Table 1.9.2 Inventory of Public Schools in the Kathmandu Valley

School Type	District			No. of Buildings						Structural Type					Stories					Age(Years)							Area				
	Muni	VDC	No.	Total	1	2	3	4	5-	1	2	3	4	5	1	2	3	4	5	0-10	-20	-30	-40	-50	50-	UN	-20	-50	-100	-200	200-
Kathmandu										Stone	Adobe	**BM**	**BC**	**RC**																	
PS	19	53	72	104	47	20	4	1	0	15	15	21	43	10	80	20	4	0	0	39	34	16	5	5	0	5	16	28	34	23	3
LS	12	14	26	62	9	7	4	3	3	5	10	24	15	8	33	24	4	1	0	21	20	11	5	0	5	0	13	13	25	9	2
SS	35	43	78	238	14	16	22	14	12	21	45	71	66	35	128	79	21	8	2	79	58	44	31	12	6	8	50	31	61	66	30
HS	3	3	6	26	0	1	0	2	3	1	2	14	7	2	11	13	0	1	1	5	8	6	1	0	0	6	2	3	8	8	5
subtotal	69	113	182	430	70	44	30	20	18	42	72	130	131	55	252	136	29	10	3	144	120	77	42	17	11	19	81	75	128	106	40
Lalitpur																															
PS	23	8	31	59	10	16	4	0	1	11	24	13	10	1	52	5	1	1	0	12	16	12	3	1	0	15	28	11	11	6	3
LS	7	3	10	24	1	6	1	2	0	2	4	12	5	1	18	3	3	0	0	5	7	5	2	1	0	4	5	3	10	5	1
SS	11	10	21	89	2	3	4	4	8	1	27	44	13	4	65	20	3	1	0	10	12	24	9	3	8	23	24	7	29	21	8
HS	2	0	2	13	0	0	0	0	2	0	5	4	3	1	7	5	1	0	0	4	1	1	2	0	0	5	5	1	1	6	0
subtotal	43	21	64	185	13	25	9	6	11	14	60	73	31	7	142	33	8	2	0	31	36	42	16	5	8	47	62	22	51	38	12
Bhaktapur																															
PS	45	21	66	99	40	22	3	0	1	5	28	38	23	5	68	25	5	0	1	26	33	19	4	2	1	14	28	19	34	17	1
LS	13	5	18	42	5	5	5	3	0	2	15	24	0	1	26	12	4	0	0	11	5	7	5	2	0	12	12	6	11	10	3
SS	6	11	17	56	3	4	2	4	4	0	11	27	11	7	32	18	5	1	0	13	16	13	7	4	3	0	10	7	19	13	7
HS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
subtotal	64	37	101	197	48	31	10	7	5	7	54	89	34	13	126	55	14	1	1	50	54	39	16	8	4	26	50	32	64	40	11
Grand Total	176	171	347	812	131	100	49	33	34	63	186	292	196	75	520	224	51	13	4	225	210	158	74	30	23	92	193	129	243	184	63
PS(Primary)	87	82	169	262	97	58	11	1	2	31	67	72	76	16	200	50	10	1	1	77	83	47	12	8	1	34	72	58	79	46	7
LS(Lower.S.)	32	22	54	128	15	18	10	8	3	9	29	60	20	10	77	39	11	1	0	37	32	23	12	3	5	16	30	22	46	24	6
SS(Secondary)	52	64	116	383	19	23	28	22	24	22	83	142	90	46	225	117	29	10	2	102	86	81	47	19	17	31	84	45	109	100	45
HS(Higher S.)	5	3	8	39	0	1	0	2	5	1	7	18	10	3	18	18	1	1	1	9	9	7	3	0	0	11	7	4	9	14	5

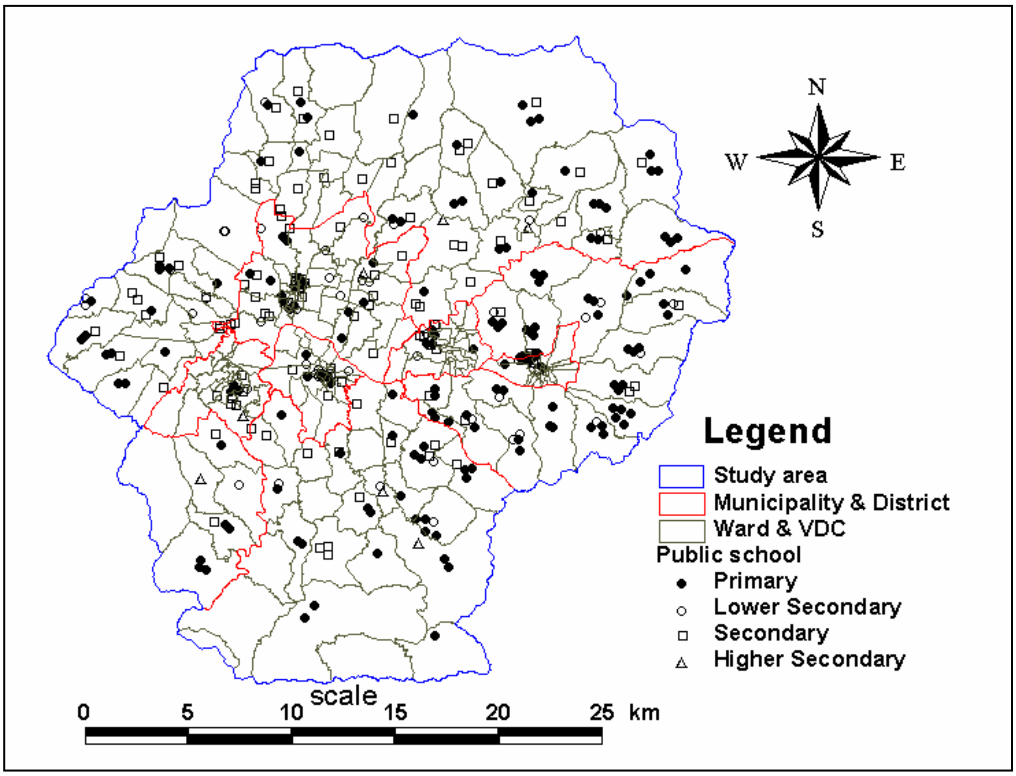


Figure 1.9.1 Public Schools in the Kathmandu Valley

The estimated damages are summarised in Table 1.9.3.

Table 1.9.3 Damage of Schools

Scenario Earthquake	Heavily	Partly	Total
Mid Nepal Earthquake	74 (22%)	102 (30%)	196 (57%)
North Bagmati Earthquake	20 (6%)	37 (11%)	57 (17%)

The damage ratio for schools is worse than that for residential buildings. The structure type ratios for schools and residential buildings are shown in Figure 1.9.2. The percentage of comparatively weak structure types of schools is higher than that of residential buildings. That is why the damage ratio of schools is high. This result would indicate that school buildings could not be used for shelters after an earthquake. Furthermore, it should be kept in mind that many children in the school would suffer if the earthquake would occur in daytime on a weekday.

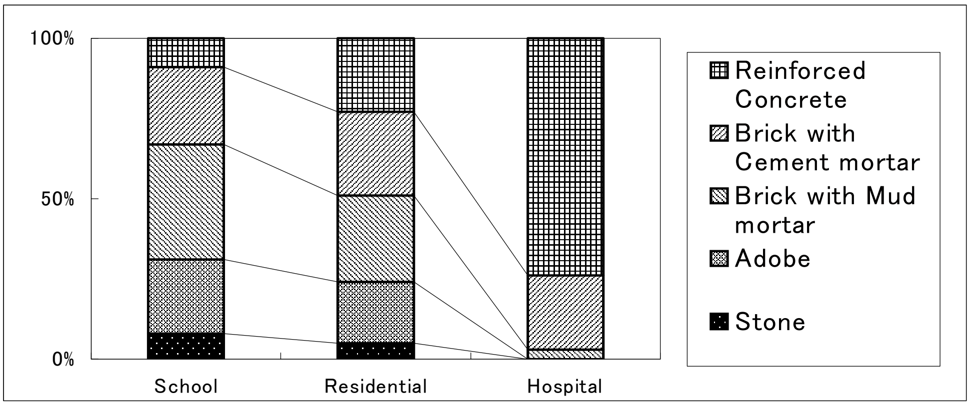


Figure 1.9.2 Structure Type ratio of School, Residential Building and Hospital

1.9.2 Hospitals

There are 47 hospitals in the Kathmandu Valley as shown in Table 1.9.4. However, as shown in Figure 1.9.3, they are distributed almost entirely inside the municipalities. Only 3 are locating in the sub-urban areas or the historical settlement. The types of hospitals are governmental, teaching, private and non-governmental. The number of buildings is usually one or two for each hospital. The buildings are 3 or 4 storied of brick with cement mortar or reinforcement that will be less vulnerable to earthquakes as shown in Figure 1.9.3, although fixtures, lifelines or furniture are still vulnerable. Most of the hospitals were built within the past 20 years, and the numbers of doctors are around 1,500 and nurses, around 2,000.

Table 1.9.4 Inventory of Hospitals in the Kathmandu Valley

Hospital Type	District			No. of buildings						Structural Type					No. of Stories					Age (Years)							Doctor	Nurse
	Muni	VDC	No.	Total	1	2	3	4	5-	1	2	3	4	5	1	2	3	4	5-	0-1	-20	-30	-40	-50	50-	UN		
Kathmandu										Stone	Adobe	BM	BC	RC														
GH	8	0	8	22	1	3	2	1	1	0	0	2	7	13	3	7	7	3	2	3	8	3	5	1	0	2	479	645
TH	2	1	3	5	2	0	1	0	0	0	0	0	1	4	2	0	0	1	2	3	1	0	0	0	0	1	402	491
PH	19	0	19	35	10	5	2	1	1	0	0	0	7	28	4	5	8	16	2	5	3	0	0	0	0	27	462	333
NH	2	2	4	5	3	1	0	0	0	0	0	0	2	3	0	1	0	2	3	1	1	0	0	0	0	3	21	65
subtotal	31	3	34	67	16	9	5	2	2	0	0	2	17	48	9	13	15	22	9	12	13	3	5	1	0	33	1364	1534
Lalitpur																												
GH	2	0	2	3	1	1	0	0	0	0	0	0	2	1	1	1	0	1	0	0	1	0	0	0	0	2	65	265
TH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PH	5	0	5	8	3	1	1	0	0	0	0	0	0	8	0	1	4	2	1	6	2	0	0	0	0	0	97	151
NH	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
subtotal	7	0	7	11	4	2	1	0	1	0	0	0	5	9	1	2	4	3	1	6	3	0	0	0	0	2	162	416
Bhaktapur																												
GH	3	0	3	10	0	2	0	0	1	0	0	1	2	7	7	2	1	0	0	2	6	1	0	0	0	1	21	40
TH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PH	2	0	2	2	2	0	0	0	0	0	0	0	0	2	0	0	1	1	0	2	0	0	0	0	0	0	3	1
NH	1	0	1	2	1	1	0	0	0	0	0	0	0	2	1	1	0	0	0	2	0	0	0	0	0	0	5	7
subtotal	6	0	6	14	3	3	0	0	1	0	0	1	2	11	8	3	2	1	0	6	6	1	0	0	0	1	29	48
Grand Total	44	3	47	92	23	14	6	2	4	0	0	3	24	68	18	18	21	26	10	24	22	4	5	1	0	36	1555	1998
GH(Governmenta)	13	0	13	35	2	6	2	1	2	0	0	3	11	21	11	10	8	4	2	5	15	4	5	1	0	5	565	950
TH(Teaching)	2	1	3	5	2	0	1	0	0	0	0	0	1	4	2	0	0	1	2	3	1	0	0	0	0	1	402	491
PH(Private)	26	0	26	45	15	6	3	1	1	0	0	0	7	38	4	6	13	19	3	13	5	0	0	0	0	27	562	485
NH(Non-Gov)	3	2	5	7	4	2	0	0	1	0	0	0	5	5	1	2	0	2	3	3	1	0	0	0	0	3	26	72

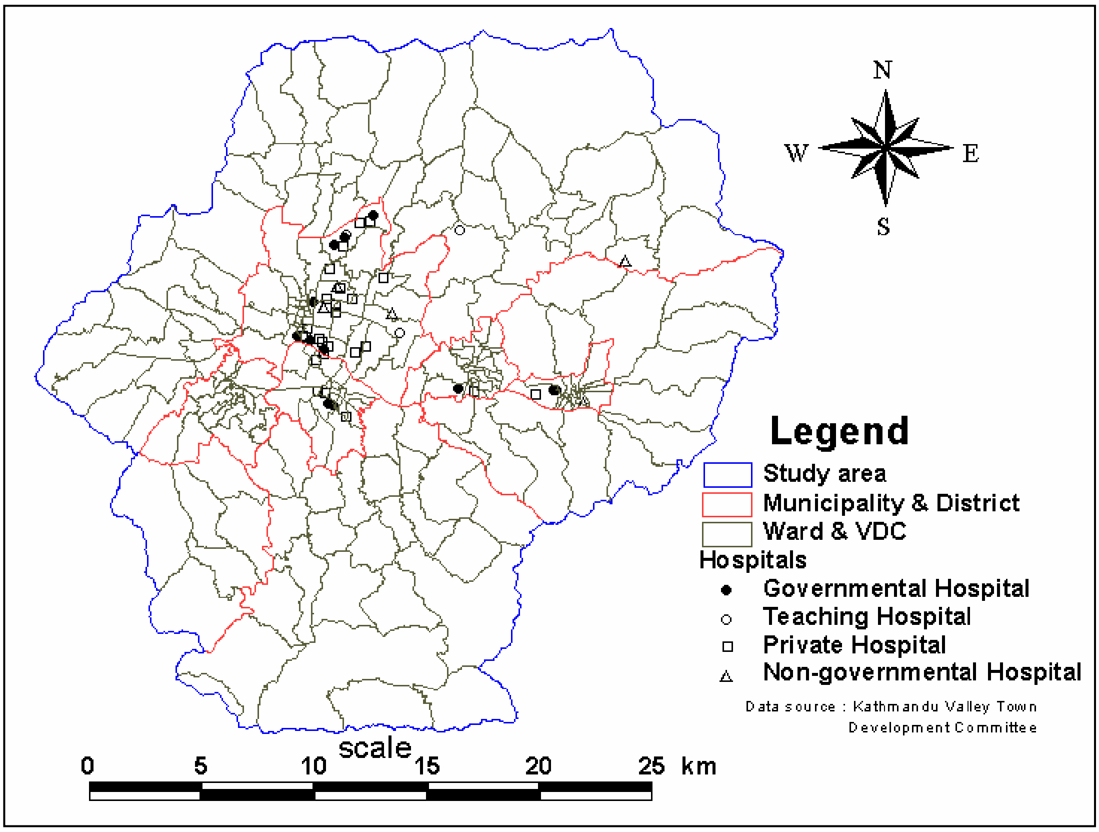


Figure 1.9.3 Hospitals in the Kathmandu Valley

The estimated damages are summarised in Table 1.9.5.

Table 1.9.5 Damage of Hospitals

Scenario Earthquake	Heavily	Partly	Total
Mid Nepal Earthquake	5 (11%)	12 (26%)	17 (36%)
North Bagmati Earthquake	1 (2%)	4 (9%)	5 (11%)

The damage ratio for hospitals is lower than that for residential buildings due to the type of buildings. As shown in Figure 1.9.2 of the previous section, the main type of hospital is relatively strong RC.

1.9.3 Fire Stations

There are only three fire stations in the Valley. They are located in Kathmandu, Lalitpur and Bhaktapur municipality as shown in Figure 1.9.4. The structure type of all station buildings is Brick with Cement mortar or Brick with Lime mortar. The estimated damages are summarised in Table 1.9.6.

Table 1.9.6 Damage of Fire Stations

Scenario Earthquake	Heavily	Partly	Total
Mid Nepal Eq.	8%	37%	45%
North Bagmati Eq.	1%	13%	14%

This result indicates that it might be possible to dispatch fire engines to fire scenes after an earthquake, although the number would not be sufficient.

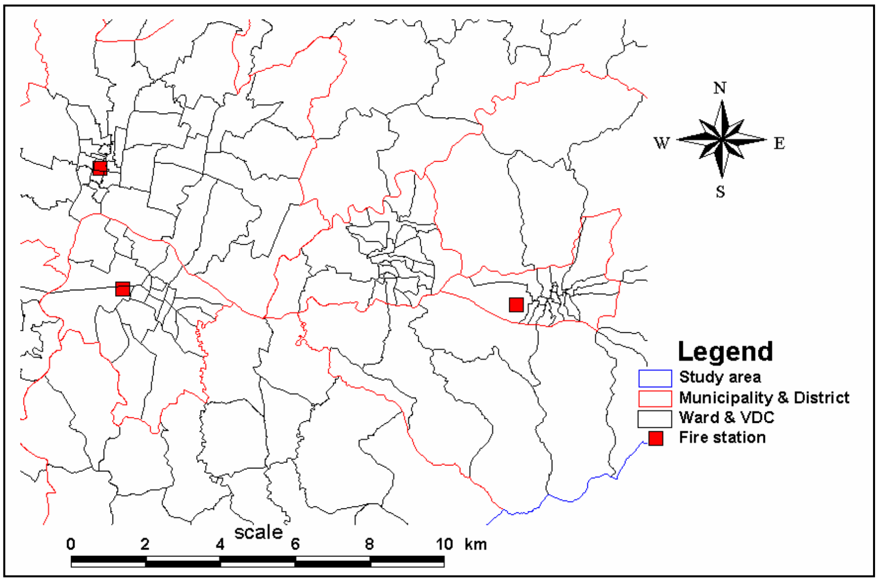


Figure 1.9.4 Fire Stations in the Kathmandu Valley

1.10 Casualties

1.10.1 Analysis Method

Building collapse was the most notable cause of human casualty in past earthquakes, such as the Kobe and Gujarat earthquakes. Slope failure and fire are other causes of human casualty, but they will not be major causes in case of the Kathmandu Valley, because records of the 1934 Bihar-Nepal earthquake show neither large-scale slope failures nor big fires. Therefore, the human casualties caused by building collapse were taken into account in the Study.

To estimate the death toll, the empirical relation between the number of heavily damaged buildings and death toll was used. This empirical relation is strongly affected by the number of residents in one building and the ratio of fatalities to the number of residents. This condition is different by country or area, so the data in Nepal were used in this study. Figure 1.10.1 shows the relation between heavily damaged or collapsed building number and death toll from the 1934 Bihar-Nepal earthquake and the 1988 Udayapur earthquake.

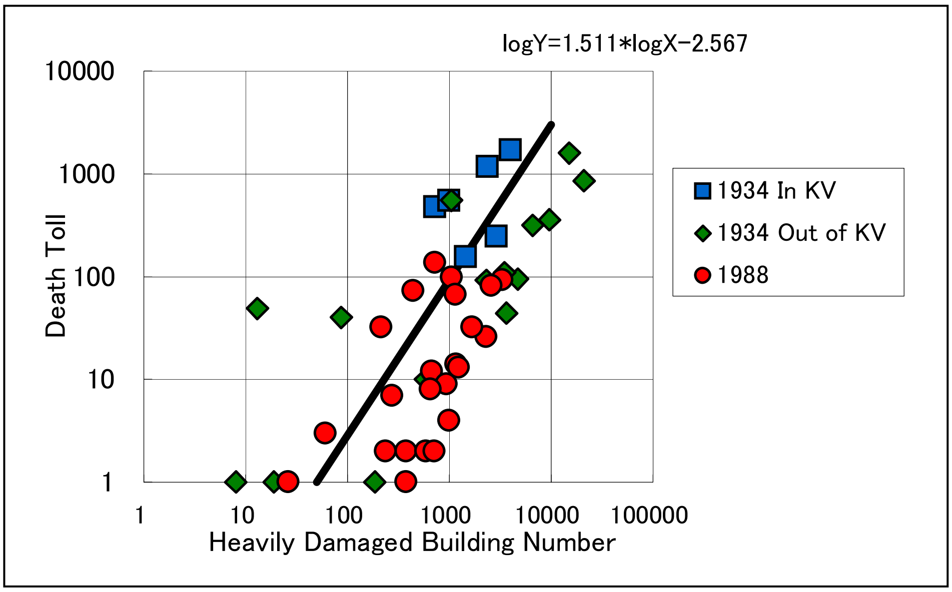


Figure 1.10.1 Empirical Relation of Building Damage and Death Toll in Nepal

These data of building damage and death toll were from Niranjan Thapa(1988) and Pandey et al. (1988). The death toll in the Kathmandu Valley in the 1934 earthquake is rather larger than the others. The concentrated building distribution in the Valley may be the reason for this difference. The black line defined by least square method in Figure 1.10.1 is the empirical relation that was used to calculate the death toll in this study.

To estimate the number of injured people, the empirical relation between death toll and number injured is adopted. Figure 1.10.2 shows the relation of the seriously injured or moderately injured and the death toll from the 1988 Udayapur earthquake.

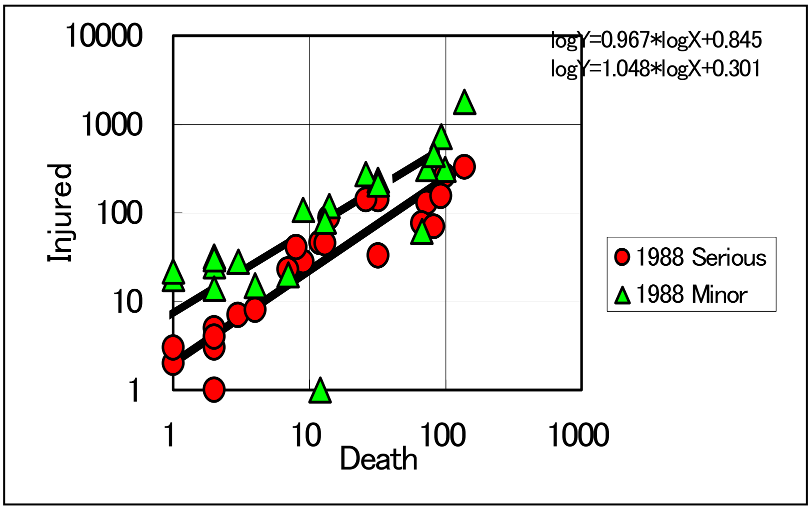


Figure 1.10.2 Empirical relation between Death Toll and Injured in Nepal

1.10.2 Estimation of Casualties

The death toll and number of the injured due to the scenario earthquakes were estimated. The cause of casualties is only building collapse and not because of any other cause. In large-scale earthquakes, people might die from diseases in refugee camps but this source of casualty was not included in the assumption. The definition of the estimation is shown in Table 1.10.1.

Table 1.10.1 Definition of Casualty Estimation

Casualties	Death, Seriously Injured, Moderately Injured
Unit	Person
Cause of Damage	Collapse of Buildings

The casualties were calculated for each ward and VDC. The results are shown in attached Figures 1.10.3 to 1.10.8, and summarised in Table 1.10.2.

Table 1.10.2 Estimated Casualties

Scenario Earthquake	Death	Injured	
		Seriously	Moderate
Mid Nepal Earthquake	17,695 (1.3%)	53,241 (3.8%)	93,633 (6.7%)
North Bagmati Earthquake	2,616 (0.2%)	7,204 (0.5%)	14,709 (1.1%)
KV Local Earthquake	14,333 (1.0%)	42,667 (3.1%)	76,399 (5.5%)
1934 Earthquake in present	19,523 (1.4%)	58,728 (4.2%)	103,313 (7.4%)
1934 Earthquake in 1934	3,814 (1.3%)	10,635 (3.6%)	21,263 (7.2%)

The characteristics of the casualties for each scenario earthquakes are as follows:

a) Mid Nepal Earthquake

The death toll is estimated as 18,000, i.e. 1.3% of the total people in the Valley. The seriously injured people are about 53,000. The number of fatalities in Ward/VDC is largest in the Kathmandu Municipality. The density of both death toll and total casualties is large in the core areas in the Kathmandu, Lalitpur and Bhaktapur municipalities.

b) North Bagmati Earthquake

The death toll is estimated as 2,600, namely 0.2% of the total people in the Valley. The seriously injured people are 7,200. The number of fatalities in Ward/VDC is large in the north of the Kathmandu Municipality. The Valley would experience the smallest damage in five scenario earthquakes.

c) KV Local Earthquake

The death toll is estimated as 14,000, namely 1.0% of total people in the Valley. The seriously injured people are about 43,000. The density of both death toll and total casualties is large in the core areas in the Kathmandu, Kirtipur, Lalitpur and Bhaktapur Municipalities. The Ward/VDC around the model fault is seriously affected.

d) 1934 Earthquake in present

The death toll is estimated as 20,000, i.e. 1.4% of total people in the Valley. The seriously injured people are 59,000. The number of fatalities in Ward/VDC is largest in the Kathmandu Municipality. The density of both death toll and total casualties is large in the core areas in the five municipalities. The Valley would suffer the largest damage in this one of the five scenario earthquakes.

e) 1934 Earthquake in 1934

The death toll is estimated as 3,800 and the seriously injured people are about 11,000. The density of both death toll and total casualties is large in the core areas in Kathmandu, Lalitpur and Bhaktapur Municipalities.

1.10.3 Validation

In this section, the relations between building damages and human casualties calculated in this study are compared with the relations of previous earthquakes in order to check whether the calculation results accord with the general relation.

Coburn and Spence (1992) surveyed worldwide earthquake damages to identify the relationship between building damages and human casualties as shown in attached Figure 1.10.9. The general trend of the relationships and the results of the Study are added onto this figure. "Building damages" consist of only heavily damaged buildings, excluding buildings destroyed by fire or tsunami. In cases where the number of damaged buildings is 1,000, the number of deaths will range from zero to 1,000. This range of distribution decreases as the number of heavily damaged buildings increases.

The most serious earthquake resulting in the largest number of casualties of the century was the Tangshan Earthquake in China in 1976, which killed 240,000 people and heavily damaged one million buildings. The number of deaths compared to building damage is high if the deaths are caused from the collapse of RC high rise buildings, such as in the 1985 Mexico City earthquake and the 1986 Armenia earthquake. The ratio of fatalities to building damage is low in the case of Japanese timber frame buildings because spaces remain if the building collapses. The relationship for weak masonry is positioned between the upper and lower trend lines. The 1975 Haicheng earthquake is an exception because this earthquake was predicted.

Five earthquake scenarios were prepared in this Study. In all cases, the relationship between the number of damaged buildings and the number of deaths agrees with those of weak masonry.

1.11 Damage to Roads and Bridges

1.11.1 Bridges

(1) Bridge Data

Until recently, most of the bridges in the Kathmandu Valley were old, having been constructed during the past 50 to 80 years. However, a total of about 11 major bridges were reconstructed by the Grant Aid assistance from the Government of Japan during the period from 1992 to 1995 and 4 bridges were reconstructed with the assistance of the World Bank.

According to the DOR classification, structures of more than 6m length are classified as bridges. A total of 54 bridges, 33 in Kathmandu District, 10 in Lalitpur District and 11 in Bhaktapur District exist according to the DOR database. Most of the bridges were built with different foreign assistance, mainly from the Government of China (17 bridges), Japan (11 bridges), the World Bank (4 bridges), India (2 bridges) and England (1 bridge). A uniform bridge design standard does not exist and most bridges are based on the design standard of the assisting foreign country. Most of the bridges around the Ring Road and other major links are badly affected by excessive scouring around the foundations of the piers due to lowering of the riverbed. The scouring is severe in the bridges upstream of the Bagmati, Bishnumati and Dhobikhola Rivers.

The inventory database of bridges in the Valley was obtained from the Bridge Unit of DOR. The bridge and river name, length of bridge, spans, foundation type etc., were included in the database, but the geometric location (co-ordinates) were not available. The co-ordinates were derived from the digital data of the Kathmandu Valley provided by KUDP. The locations of bridges are shown in attached Figure 1.11.1.

An inventory survey was also carried out to obtain further information needed for damage estimation and planning that was not available in the DOR database and also to verify the actual conditions. The inventory sheet, including the following items, was prepared for the survey work

a) Girder type
b) Bearing type
c) Maximum height of abutment/pier
d) Number of spans
e) Condition of bridge seat width
f) Foundation type

g) Material of abutment/pier
h) Scouring
i) Possibility of access road

(2) Damage Estimation Method

The seismic damage possibility judgement of the bridge is based on the method proposed by Tsuneo Katayama. The method, which was prepared by the Disaster Prevention Council of the Tokyo Metropolitan Area (1978), is widely used in Japan for practical purposes. This technique was obtained by multi-dimensional quantification theory I, based on actual earthquake disasters. The evaluation is based on the following factors:

a) Ground type (0.5 – 1.8)
b) Liquefaction (1.0 – 2.0)
c) Girder type (1.0 – 3.0)
d) Number of individual girder (1.0 – 1.75)
e) Bearing (0.6 – 1.15)
f) Minimum bridge seat width (0.8 – 1.2)
g) Maximum height of abutment and pier (1.0 – 1.7)
h) Earthquake intensity scale (1.0 – 3.5)
i) Foundation type (1.0 – 1.4)
j) Material of abutment and pier (1.0 – 1.4)

The numbers in parenthesis are the score range for each factor according to the bridge condition. The score of each factor is decided by the field reconnaissance of the Study Team. The results of the analyses are expressed as the product of the ten scores, one for each category. Judgement of the stability of bridges is generally defined as follows:

a) Score 26 and above: Collapsed
b) Score below 26: Stable

(3) Damage Estimation

The results of the damage estimation for the bridges are shown in attached Figure 1.11.2, and summarised in Table 1.11.1.

Some bridges in the Valley are badly affected by excessive scouring around the foundation of the piers. The method of Katayama does not take scouring into account; however, excessive scouring will reduce earthquake resistance because piers will have lower resistance to lateral forces. It is difficult to estimate the effect of scouring quantitatively; therefore, the bridges that are excessively scoured and achieved a score over 20 are listed as “Unstable” bridge in this study.

Table 1.11.1 Results of Damage Analysis for Bridges

No.	Identity	Name	Road	Score	Scouring	Judgement
6	3/H3/4+390	Manahara	H3 - Arniko Rajmarg	46	Very High	Collapse
10	14/A	Bishnumati, Paropakar	K T M Urban Road	27	No	Collapse
13	2/H3/2+390	Bagmati	H3 - Arniko Rajmarg	46	Very High	Collapse
17	2/R/5+000	Dhobi Khola	K T M Ring Road	27	Yes	Collapse
20	1/H2/2+000	Bishnumati, Kalimati	H2 - Tribhwan Rajpath	46	No	Collapse
23	1/H3/0+800	Dhobi Khola	H3 - Arniko Rajmarg	27	Very High	Collapse
25	15/A	Bishnumati, Kuleshwor	K T M Urban Road	40	No	Collapse
36	4/A	Bagmati, Thapathali	K T M Urban Road	52	Protected	Collapse
37	1/D	Godawari	Imadol - Tikathali	32	No	Collapse
38	5/R/17+000	Balkhu	K T M Ring Road	29	Very High	Collapse
39	2/D/4+200	Godawari	Gorkhu - Lubhu	41	No	Collapse
48	4/H3/8+850	Hanumante	H3 - Arniko Rajmarg	41	Yes	Collapse
54	1/DR/0+200	Hanumante	Thimi-Dadhikot-Suryabinayak	32	No	Collapse
19	11/A	Bishnumati, Balaju	K T M Urban Road	22	Very High	Unstable
28	1/R/3+200	Bagmati, North	K T M Ring Road	22	Very High	Unstable

1.11.2 Roads

(1) Road Data

Digital data of the Valley has been prepared by the Kathmandu Valley Town Development Committee (KVTDC, Ministry of Physical Planning and Works) under the “Kathmandu Valley Urban Development Project (KUDP)” in 1998 and “Development Plan 2020 of the Kathmandu Valley” in 2000. These data consist of road network data in AutoCAD file format as well as ArcView GIS file format. However, the network was separated into only two types of road classification, Metalled Road and Un-metalled Road, in the AutoCAD drawing. These data were used to classify the road into the DOR classification. The Nepal Road Statistics (NRS-1998) published by DOR was referred to for the road classification. The following classes were formed and the data for each class of road was created into separate layers.

a) National Highway.
b) Feeder Road, Major.
c) Feeder Road, Minor.
d) District Road Bituminous.
e) District Road Gravel/Earthen.
f) Ring Road (additional class in this project; DOR classification is Urban Road).
g) Urban Road Major (Only Urban Road in DOR classification).
h) Urban Road Minor.
i) Urban Road Gravel.

A separate classification for the Ring Road was included considering its greater importance from an earthquake disaster viewpoint. Similarly, separation of urban roads into major and minor was also based on their level of importance during earthquake disasters. The limit of the KUDP data is less than the Kathmandu Valley watershed boundary that is the boundary limit of this project. The KUDP data covers all the urban and sub-urban areas except for some of the rural areas near the boundary limits. These data outside the KUDP limits were obtained from the "Kathmandu Valley GIS Database" of the International Center for Integrated Mountain Development (ICIMOD), 2000. The classification used by ICIMOD is also different (Highway, Major Road and Feeder Road) and hence was changed to the project classification for the additional data included from the ICIMOD database. It is quite difficult to classify the road network based on road width, mainly because no standard is applied for the construction of urban roads and the width of roads varies greatly even within a short segment. In consideration of this, the following road widths were applied for each road classification based on their design drawing and/or observed data as given in Table 1.11.2.

Table 1.11.2 Applied Road Widths

S.N.	Road Class	Applied Width
1	National Highway	7.0 m
2	Feeder Road Major	6.0 m
3	Feeder Road Minor	4.5 m
4	District Road Bituminous	4.5 m
5	District Road Gravel/Earthen	3.0 m
6	Ring Road	10.0 m
7	Urban Road Major	12.0 m
8	Urban Road Minor	4.0 m
9	Urban Road Gravel	2.5 m

Though the road width of the National Highway is only 7m, the Right-of-Way (ROW) is significantly large (more than 15m on either side) outside of the Ring Road. Similarly, the Ring Road also has 25m ROW on either side of the road. The theoretical ROW of the Feeder Roads is 15m on both sides. However, the ROW has been encroached by buildings in the urbanised areas. On the contrary, both sides of the urban roads are heavily built-up and no definite ROW is available. The road network is shown in attached Figure 1.11.3.

(2) Damage Estimation

There are no roads with thick fill-embankment in the Valley. In this study, the points where roads cross the slopes whose height is over 50m, which are identified in section 1.5, are pointed out as hazardous points. Attached Figure 1.11.4

shows the hazardous points of the National Highway, Feeder Road Major, Feeder Road Minor, District Road Bituminous, Ring Road and Urban Road Major, which will be used as emergency access roads after disaster.

1.11.3 Accessibility

Attached Figure 1.11.5 shows the accessibility of National Highway, Feeder Road Major, Feeder Road Minor, District Road Bituminous, Ring Road and Urban Road Major after Mid Nepal earthquake based on above analysis. In this figure, all the hazardous points of roads are estimated to collapse. The National Highway, which is the sole road to other parts of the nation, may not be used right after the earthquake because of slope failure, although the recovery will be quicker than from bridge collapse.

1.12 Damage to Lifeline Facilities

The following four lifeline facilities are considered in this section:

a) Water supply pipelines.
b) Sewerage pipelines.
c) Electric power supply lines.
d) Telecommunication lines.

Lifeline facilities are to be classified into two major categories, nodes and links. Nodes include facilities such as purification plants and substations. Links include facilities such as pipes or lines for supply and distribution purposes. A statistical approach for damage estimation of links, i.e. distribution pipes and lines, is applied in the Study. Damages for the node facilities were not estimated in the Study, because a statistical approach of this analysis is not applicable for such structures. Separate detailed surveys are required for the damage estimation of the node facilities.

1.12.1 Water Supply Pipelines

(1) Water Supply Data

Data regarding water supply and sewerage systems are the most difficult to collect. Detailed drawings of the distribution network are not available since these were constructed at different periods of time without any plan.

A paper drawing was available for the distribution pipe network of the Kathmandu and Lalitpur urban areas that was prepared by the NWSC, CES Report. The drawing was scanned and converted to digital format. Layers were separated according to the diameter of pipe. Primary and secondary networks are not distinguishable from the available data. The material of the pipe was also not available in the drawing. Basically, there seems to be mainly four types of existing pipes according to the material classification, which are as follows:

GI: Galvanised Iron, used mainly for distribution and diameter less than equal to 50mm.

CI: Cast Iron, relatively brittle and used mainly for diameter greater than 50 mm.

DI: Ductile Iron, relatively better and used for higher diameter.

HDPE: High-density polyethylene, better against horizontal forces due to its flexibility but construction of joints is difficult and poor.

Digital data showing the locations of the main water sources (both surface and ground) in the Kathmandu Valley was collected from the Melamchi Project Data. The location of intakes, reservoirs, treatment plants and other ground water wells are also shown in the drawing. The distribution network data of Bhaktapur and Madyapur municipalities was available from a recent study report, NWSC, Design of Rehabilitation and Extension Works of Bhaktapur Water Supply System, prepared by Nepalconsult/Cemat. The water supply network is shown in attached Figure 1.12.1.

(2) Damage Estimation Method

No quantitative studies on seismic damage for water supply pipelines in Nepal were available. Although the strength of the pipeline materials is not particularly different from that of the pipeline materials in other countries, it is considered that the construction quality of the joints always leads to problems.

Kubo and Katayama (1975) proposed a relationship between peak ground acceleration and the damage ratio of water supply pipelines from experience in Japan, USA and Nicaragua, as shown in Figure 1.12.2. This figure also shows the damage function for distribution pipelines from ATC-13 that was originally compiled to estimate seismic damage in California, USA, using historical earthquake damage records.

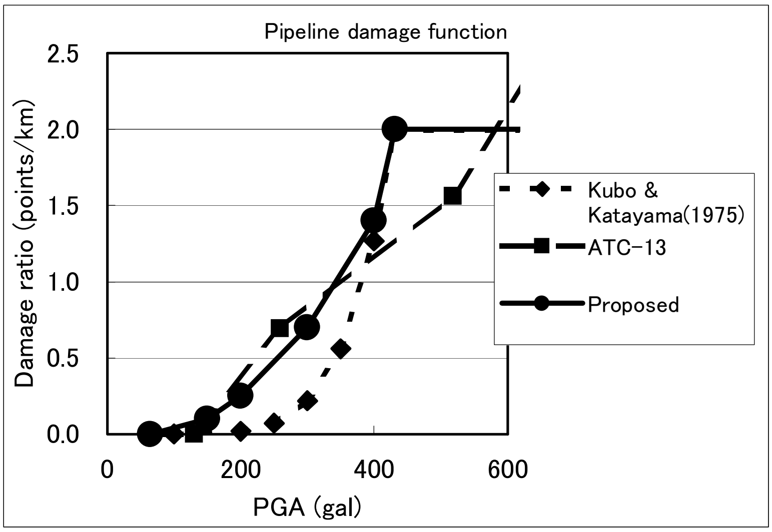


Figure 1.12.2 Damage Function of Water Supply Pipelines by PGA

In this study, a new damage function was used, as shown in Figure 1.12.2. This damage function estimates a higher damage ratio than that of Kubo and Katayama (1975) because the construction quality in Nepal is poorer than in Japan, according to our field reconnaissance. But this new damage function is almost the same as that of ATC-13.

This relation was formulated as follows (for example, Kubo and Katayama, 1981):

Rfm = Rf x Cg x Cl x Cp x Cd

where

Rfm: damage ratio (points/km)
Rf = 1.7 x $A^{6.1}$ x 10^{-16}
in case of Rf > 2.0, Rf should be 2.0
A: acceleration (gal)
Cg: ground condition coefficient
2.0 for soft soil
Cl: liquefaction coefficient
1.0 for $P_L=0$
1.2 for $0 < P_L <= 5$
1.5 for $5 < P_L <= 15$
3.0 for $15 < P_L$
Cp: pipeline material coefficient
1.0 for CI (Cast Iron)
0.2 for DI (Ductile Iron)
1.0 for GI (Galvanised Iron)
1.5 for HDPE (PVC)
2.0 for Steel
Cd: pipeline diameter coefficient
1.0 for less than 180 mm
0.6 for 180 mm to 300 mm
0.4 for over 300 mm

This formula was used in the Study. Based on the above examination, the proposed damage function in Figure 1.12.2 was used instead of Rf.

(3) Damage Estimation

The damage estimation definition is as shown in Table 1.12.1.

Table 1.12.1 Definition of Pipeline Damage Estimation

Object	Distribution Pipeline
Content of Damage	Break of pipelines or joints
Amount of Damage	Number of damage points

The results of the damage estimations are show in attached Figure 1.12.3 and summarised in Table 1.12.2.

Table 1.12.2 Estimated Damage of Water Supply Pipelines

Scenario Earthquake	Damage points
Mid Nepal Earthquake	588
North Bagmati Earthquake	63

1.12.2 Sewerage

(1) Sewerage Data

A paper drawing, similar to that of the water supply lines, is available showing the size of the pipes. The sewerage data also covers mainly the urbanised area and inside of Ring Road. The drawing was scanned and converted to digital format and layers were separated for each pipe diameter classification. Basically, there seem to be two types of material for the sewer lines. One is brick channel (oval or open rectangular), and the other is the Pre-Cast (PC) concrete pipe. Some of the brick channels are very old dating back to Rana Period. New pipelines are mainly the PC concrete types.

A separate drawing was available from the CES Report in which the brick channels and the piped sewers were clearly marked (prepared after their site survey) and was used for identifying the brick and piped sewers. The Kathmandu Valley Mapping Project by KMC is currently preparing a comprehensive database but covers only 35 wards of Kathmandu Metropolitan City. The sewerage network data is shown in attached Figure 1.12.4.

(2) Damage Estimation Method

The evaluation formula used for sewerage pipelines was the same as that for water supply pipelines. Data were provided on the type and diameter of the pipes, and the following values were used for each factor based on figures which are currently used in Japan.

Cg: ground condition coefficient
    2.0 for soft soil
Cl: liquefaction coefficient

1.0 for $0 < = P_L <= 5$
2.9 for $5 < P_L <= 15$
7.0 for $15 < P_L$

Cp: pipeline material coefficient
1.0 for Brick Channel
0.5 for PC

Cd: pipeline diameter coefficient
0.6 for less than 500 mm
0.4 for 500 to 900 mm
0.2 for over 900 mm

(3) Damage Estimation

The damage estimation definition is shown in Table 1.12.3.

Table 1.12.3 Definition of Sewerage Damage Estimation

Object	Pipeline and channel
Content of Damage	Break of pipelines or joints
Amount of Damage	Number of damage points

The results of the damage estimations are show in attached Figure 1.12.5, and summarised in Table 1.12.4.

Table 1.12.4 Estimated Damage of Sewage Pipelines

Scenario Earthquake	Damage points
Mid Nepal Earthquake	52
North Bagmati Earthquake	5

1.12.3 Electric Power Supply

(1) Electricity Data

The transmission line network in the Kathmandu Valley was obtained from the Transmission Line Department of the Nepal Electricity Authority (NEA). The data were obtained as paper maps. The location of substations and the transmission line network with different high voltage classifications were marked on the paper map. The following high voltage lines were indicated in the drawing:

a) 132 kV transmission line.
b) 66 kV transmission line.
c) 11 kV transmission line.

A 33 kV transmission line exists in Bhaktapur. Based on the information of the Transmission Line Department of NEA, although this line was constructed for 33 kV, actual transmission is at only 11 kV. So this line was also included in the 11 kV transmission line network.

The paper map was then scanned and converted to digital format. Layers for each high voltage class were created and a separate layer was also created for substations. The digital data of the electricity Distribution Network was obtained from the Corporate Planning Department of NEA. The data include AutoCAD drawing files for Kathmandu, Lalitpur and Bhaktapur districts as well as the ArcView format files for the same. The distribution lines of 11 kV are included in this file with the location of transformers also. It was not possible to identify feeder lines separately from these data. It is recommended that this be updated by the concerned Department of NEA in future. The electricity network is given in attached Figure 1.12.6.

The co-ordinate system used in the drawings is not consistent. The data of Kathmandu and Bhaktapur districts seems to be in KUDP co-ordinate system format, whereas the data of Lalitpur district seems to be in KVTDC co-ordinate system. Proper transformation of the co-ordinate systems is required.

(2) Damage Estimation Method

In the Kobe Earthquake, Japan, no electric poles were damaged in areas of seismic intensity (MMI) less than VIII, whilst 0.55% of poles were broken or collapsed in areas of seismic intensity (MMI) IX and over.

Based on this experience, the damage function for electric power supply line was made by Saitama Prefecture (1998). This damage function is shown in Figure 1.12.7. The damage function of power supply lines from ATC-13 is also shown in this figure.

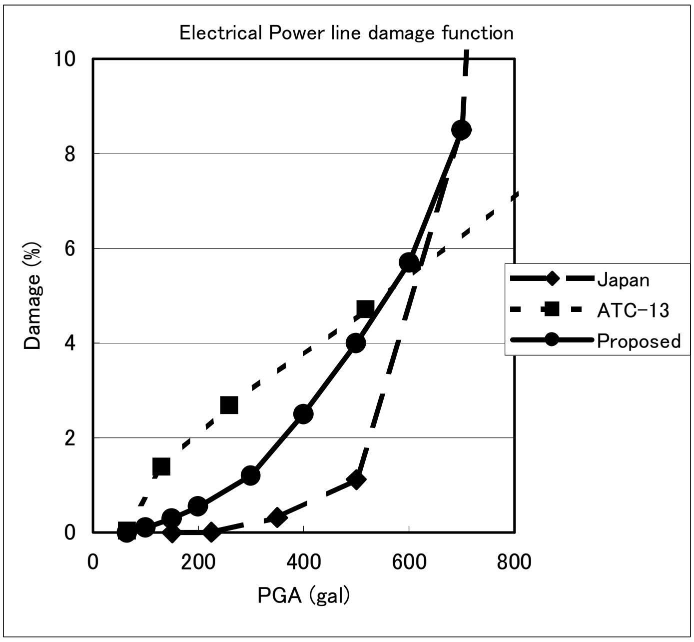


Figure 1.12.7 Damage Function of Power Supply Lines by PGA

In this study, the newly proposed damage function, shown in Figure 1.12.7, was used for analysis. This function was based on the damage from the 1988 Udayapur earthquake. Dikshit (1991) reported that several electric pylons were damaged in the area of MMI VI (approximately 65 gal after Trifunac & Brady, 1975) in the 1988 Udayapur earthquake. From this damage, the smallest PGA that may cause damage to electrical power lines was estimated to be 65 gal.

(3) Damage Estimation

There are several types of damage to electric power supply link facilities, such as breakage of poles, the falling down of transformers and severing of wires. The damage to wires is treated in this Study, because of the limitation of data availability.

The damage estimation definition is shown in Table 1.12.5.

Table 1.12.5 Definition of Damage Estimation of Power Supply Lines

Object	Electrical power lines over 11 kV
Content of Damage	Cut cables
Amount of Damage	Length of cables to be replaced

The results of the damage estimations are show in attached Figure 1.12.8, and are summarised in Table 1.12.6.

Table 1.12.6 Estimated Damage of Electric Power Supply Lines

Scenario Earthquake	Damage length (km)
Mid Nepal Earthquake	6.2
North Bagmati Earthquake	1.2

Because information about over 11 kV high voltage line was available, the damage estimation was limited to the high voltage lines. The actual damage to the low voltage lines of less than 11 kV would be much bigger, and which should be taken into consideration at the time of disaster mitigation planning.

1.12.4 Telecommunications

(1) Telecommunication Data

Data on the telecommunication network were collected from the Nepal Telecommunication Corporation (NTC), which is preparing the GIS database for its cable network. NTC has completed inputting its primary and secondary network data into GIS for most of the areas inside Kathmandu City except some percentage of the core area.

However, data input has not commenced yet for Kirtipur, Lalitpur, Madyapur and

Bhaktapur. The data for these areas are available only in the hard copy paper drawings. Only the primary network data has been used in this study that is mainly an underground network. The primary telecommunication network is shown in attached Figure 1.12.9.

(2) Damage Estimation Method

Almost all "Primary" telecommunication cables are laid underground. The damage to underground lines in the 1995 Kobe earthquake was almost half that of overhead cables in areas with the same seismic intensity. From this experience, the damage function for telecommunication lines was estimated to be half that of the electrical power line damage function.

(3) Damage Estimation

The damage estimate definition is shown in Table 1.12.7.

Table 1.12.7 Definition of Damage Estimation of Telecommunication Lines

Object	Primary line
Content of Damage	Cut of lines
Amount of Damage	Length of cables to be replaced

The results of the damage estimations are show in attached Figure 1.12.10, and are summarised in Table 1.12.8.

Table 1.12.8 Estimated Damage of Telecommunication Lines

Scenario Earthquake	Damage length (km)
Mid Nepal Earthquake	0.9
North Bagmati Earthquake	0.2

In this study, only the information about "Primary" line was available as already mentioned. Therefore, the damage estimation was limited to the "Primary" lines. The actual damage to the lower level of lines would be much bigger, which should be taken into consideration at the time of disaster mitigation planning.

1.13 Fire

There are three main fire stations in the Kathmandu Valley. They are located in Kathmandu, Lalitpur and Bhaktapur municipalities respectively. Among them, the Kathmandu office has three fire engines and 18 fire fighters on its staff. However, there is only one effective engine with 15 to 20 fire fighters in each of the other two offices. Further, since most of the engines were introduced in the 1970's and 1980's, their deterioration is a concern. Totally, over 200 fires were detected and fought in the fiscal year 2000 in the Kathmandu Valley as shown in Table 1.13.1.

Table 1.13.1 Number of Fire in the Fiscal Year 2000 at the Kathmandu Valley

Month	Causes of Fires																								
	Uncertain			Electric Shock			Kerosene Stove			Cooking Gas			Candle			In Forest			Lightning			Total			Grand Total
	K	L	B	K	L	B	K	L	B	K	L	B	K	L	B	K	L	B	K	L	B	K	L	B	
Apr	6	4	1	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	9	5	1	15
May	3	0	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	6	0	1	7
Jun	2	0	1	5	1	1	0	0	0	3	1	0	0	0	0	0	0	0	0	0	1	10	2	3	15
Jul	4	1	2	2	2	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	8	3	3	14
Aug	4	3	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	7	3	1	11
Sept	3	1	1	0	0	1	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	5	2	2	9
Oct	10	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	4	4	22
Nov	4	0	2	4	1	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	11	1	3	15
Dec	5	2	2	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	6	2	5	13
Jan	5	3	8	2	1	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	8	6	8	22
Feb	9	2	3	2	0	3	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	11	2	8	21
Mar	19	10	15	0	1	1	1	0	0	0	0	0	0	0	0	0	0	6	0	0	0	20	11	22	53
Total	74	30	40	25	7	8	1	0	3	13	4	1	2	0	0	0	0	8	0	0	1	115	41	61	217

K: Kathmandu District, L: Lalitpur District, B: Bhaktapur District

This seems a smaller number than in Japan, the reason probably being that in Nepal, the houses are built mainly of bricks without much timber. Particularly, there are no records of fires spreading to other houses at all. So, fire generally does not spread very rapidly except for forest fires. The main cause of most fires was uncertain, but, of the cases in which the cause was known, electric sparks, cooking gas, kerosene stoves and other sources of fire in the home were the main causes. Seasonally, fires are more common in winter, especially in March when there are festivals.

(1) Gas Centres and Petroleum Stations

The distribution of gas centres and petroleum stations is shown in Figure 1.13.1. There are a total of 379 petroleum stations, with 98 stations in municipalities and 281 stations in the VDCs, and there are 2 gas centres in the Kathmandu Valley. These petroleum stations sell mainly kerosene.

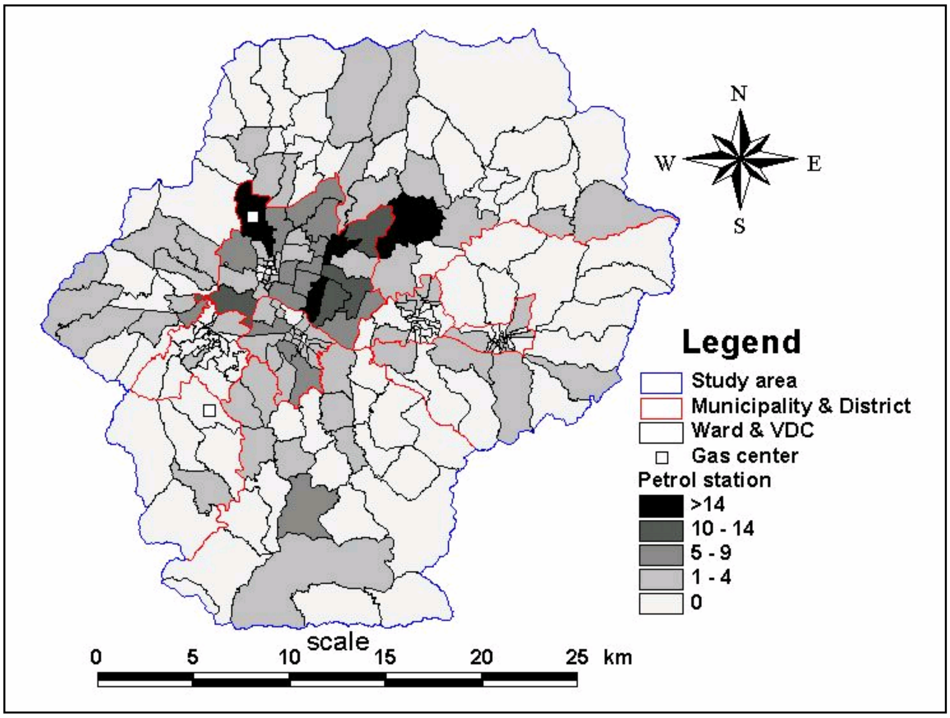


Figure 1.13.1 Gas Centres and Petroleum Stations in the Kathmandu Valley

(2) Fire Outbreak Estimation

The possibility of fire outbreaks from facilities where inflammable liquids or gases are handled was estimated. The facilities are classified as follows:

a) Petrol stations.
b) Gas refilling stations.

The concepts of the estimation are as follows:

a) The offices of the facilities will suffer damages caused by earthquake motion, and the damage functions for residential buildings were applied in the estimation of damages to office buildings.
b) Inflammable liquids or gases will leak from the storage tanks of facilities that collapse or are seriously damaged.
c) The leaking liquids or gases will ignite according to the following probability.
Petrol stations: 2.55%.
Gas refilling stations: 57.9%. (Kanagawa Prefecture 1986)
d) The above values are estimated based on Japanese experience. No information on fire occurrences in Nepal was available. Consequently, the results show only a relative possibility of fire occurrence.
e) The number of fire outbreaks is summed for each Ward/VDC and then expressed as a rating of fire hazard.

Distributions of the vulnerability rating for each Ward/VDC under the scenario earthquakes are shown in attached Figure 1.13.2.

In general, the main origins of fire outbreak after earthquakes are kitchens and heaters in residential buildings. These sources were not examined because of a lack of information regarding fire, especially after earthquake. There should be little possibility of fire spreading to other buildings because buildings are mainly made of bricks. However it should be kept in mind that many fires occur immediately after an earthquake and fires fighting capacity is severely diminished at this time. Electricity is a common cause of non-earthquake fires as shown in Table 1.13.1. It is easy to imagine that many fires will break out from the tangled electrical power lines.