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SEISMIC VULNERABILITY FOR AHMEDABAD CITY IN INDIA

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Abstract

This paper presents the results of a study on seismic vulnerability of reinforced concrete frame buildings with brick masonry infill walls as prevailing in Ahmedabad city in India in the year 2001. The study is based on the damage data of about 3,000 buildings in Ahmedabad following the 2001 Bhuj (magnitude 7.7) earthquake. The city experienced ground shaking of intensity VII (on MSK scale) during the earthquake and about 130 multistorey buildings collapsed in Ahmedabad, killing 805 persons.

The study compares damage distribution in Ahmedabad with that specified by the ATC 13 (1985) document entitled "Earthquake damage evaluation data for California". A parallel was established between the damage classification adopted in the ATC 13 document and that adopted during the survey in Ahmedabad. The damage data of buildings in Ahmedabad (due to shaking intensity VII) came closest to ATC-13 data for non-ductile RC frame buildings for shaking intensity VIII in terms of mean and median damage factors. The number of severely damaged and collapsed buildings (and hence the casualties) for Ahmedabad buildings was significantly higher than what is estimated by the ATC method even with using an increased shaking intensity of one level.

Hence, Ahmedabad buildings in 2001 were clearly far more vulnerable than the normal non-ductile buildings envisaged in ATC-13. The study implies high seismic vulnerability of building constructions in India in general, even though there may have been some improvement in the design and construction practices in Ahmedabad and in rest of India since 2001.

Keywords: Reinforced concrete buildings, Bhuj earthquake, vulnerability assessment, Ahmedabad, ATC 13

1. Introduction

The 2001 Bhuj (magnitude 7.7) earthquake resulted in a lot of damage to the reinforced concrete (RC) frame buildings with brick masonry infills in Ahmedabad city. Ahmedabad is located about 230 km from the epicenter and experienced a shaking intensity of VII on the MMI scale. Around 130 multistory buildings collapsed in the city and this caused 805 deaths in Ahmedabad. After the earthquake, a comprehensive damage survey was conducted by Centre for Environment Planning and Technology (CEPT) and damage data of about 3,000 buildings has been used as a basis for this study.

A parallel is established between the damage classification adopted during the survey in Ahmedabad with that given in the ATC 13 [1] document entitled "Earthquake damage evaluation data for California". The ATC methodology suggests increasing or decreasing the intensity of shaking in the estimation of damage to the buildings, depending on whether the building is a non-standard construction or a special construction. The present study attempts to establish whether the shaking intensity should be increased by one or two units for the buildings in Ahmedabad.

The ATC methodology is described briefly first. The damage data of approximately 3,000 buildings surveyed in Ahmedabad after the 2001 Bhuj earthquake is presented. Finally, the parallels are drawn between the damage estimation using the ATC method and the damage observed in the Ahmedabad buildings.

2. ATC methodology

Applied Technology Council (ATC) had developed a procedure to estimate earthquake damage to existing facilities in California, which was based primarily on the experience and judgement of senior earthquake engineers. The procedure is briefly discussed in the sections below.

2.1 Facility classification scheme

A total of 78 facility classes were identified in terms of size, structural system and type, 40 of which were buildings. The physical damage, defined as the percentage of replacement value, to the 78 facilities was estimated using three-round questionnaire process involving earthquake engineering experts. The facility class "moment resisting non-ductile concrete frame (distributed frame)" with low, medium and high rise (class number 87, 88 and 89, respectively) are considered relevant for the present study.

2.2 Damage states

The ATC document expresses the damage in terms of damage factor (DF), which is defined as the ratio of cost of repairing damage to the replacement value of the facility. Each damage state is assigned a damage factor range. The damage states' definitions are based on the Structural Engineers Association of California's (SEAOC) earthquake resistant design philosophy statements [2] and on the engineering judgement of experts involved in the ATC project. The seven damage states are listed in Table 1.

2.3 Damage probability matrices

The damage probability matrix (DPM) for a facility class provides the probability of being in each of the damage states for a given shaking intensity (see [3-4]). Table 2 presents the DPM for mid-rise non-ductile moment resisting frame for MMI levels VI through XII. The data in the table is based on the assumption that the distribution of damage for a given shaking intensity is described by a Beta probability distribution. The parameters for the distributions are available in the ATC 13 document.

Table 1 – Damage states defined in ATC 13 [1]

Damage State	Damage Factor Range (%)	Central Damage Factor (%)	Definition
1 (None)	0	0	No damage
2 (Slight)	0-1	0.5	Limited to localized minor damage not requiring repair
3 (Light)	1-10	5	Significant localized damage of some components generally not requiring repair
4 (Moderate)	10-30	20	Significant localized damage of many components warranting repair
5 (Heavy)	30-60	45	Extensive damage requiring major repairs
6 (Major)	60-100	80	Major widespread damage that may result in the facility being razed, demolished, or repaired
7 (Destroyed)	100	100	Total destruction of the majority of the facility

Table 2 – Damage states defined in ATC 13 for mid-rise non-ductile moment resisting frame buildings [1]

Damage State	Shaking intensity on MMI scale						
	VI	VII	VIII	IX	X	XI	XII
1	0.3	0	0	0	0	0	0
2	30.9	0.3	0	0	0	0	0
3	68.8	96.9	33.6	1.9	0.2	0	0
4	0	2.8	65.7	65.1	30.8	3.6	0.5
5	0	0	0.7	33.0	67.7	70.0	27.9
6	0	0	0	0	1.3	26.4	71.2
7	0	0	0	0	0	0	0.4

2.4 Effect of design and construction quality on damage estimation

The ATC 13 methodology was developed for the buildings in California. Three grades of quality of design and construction have been considered by ATC 13: standard, special and nonstandard construction. It has been suggested if the construction is nonstandard, the damage will be estimated using DPM by increasing the shaking intensity level by one or two units, and if the construction is special, DPM may be estimated by decreasing the shaking intensity level by one or two units.

3. Damage data of 2001 Bhuj earthquake

The design and construction in a developing country like India will likely be categorized as non-standard. In order to use the ATC 13 methodology for damage estimation, the intensity will need to be shifted up by one or two units. This section presents the damage data of the RC frame buildings in Ahmedabad, which is compared with the ATC methodology to determine whether the intensity should be scaled up, and if so, by one or two units.

3.1 Damage in Ahmedabad buildings

A shaking intensity of up to X on the MSK scale (similar to the MMI scale) was observed in the Kutch region during the 2001 Bhuj earthquake. The city of Ahmedabad, which is about 230 km away from the epicenter, experienced the shaking intensity of VII. A damage survey was conducted by the Center for Environmental Planning and Technology (CEPT) at Ahmedabad and the buildings were classified in five groups: G0 (no damage) to G5 (collapse). The damage categories are listed in Table 3, and details of these damage categories are available elsewhere [5].

Table 3 – Damage categories used to classify Ahmedabad buildings following the 2001 Bhuj earthquake [5]

Category	Description of damage
G0	No damage
G1	Slight non-structural damage
G2	Slight structural damage
G3	Moderate structural damage
G4	Severe structural damage
G5	Collapse

Survey data for 2,856 RC frame buildings are available, which included 617 low-rise (1 to 3 stories), 1690 mid-rise (4 to 7 stories) and 260 high-rise (more than 8 stories) buildings. The height was not specified for 289 buildings. Table 4 presents the percentage of buildings that suffered damages at G0 through G5 levels for low-rise, mid-rise and high-rise buildings. The percentage damage under different categories does not change materially when only low-rise, mid-rise or high-rise buildings are considered.

Table 4 – The category-wise damage data of Ahmedabad buildings

Category	Low-rise		Mid-rise		High-rise		All buildings	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
G0	61	9.9	111	6.6	7	2.7	194	6.8
G1	324	52.5	834	49.4	131	50.4	1,424	49.9
G2	195	31.6	599	35.4	107	41.2	1,013	35.5
G3	34	5.5	135	8.0	14	5.4	206	7.2
G4	2	0.3	9	0.5	0	0	12	0.4
G5	1	0.2	2	0.1	1	0.4	7	0.3
Total	617	100	1,690	100	260	100	2,856	100

3.2 Comparison with ATC-13 prediction

The ATC methodology considers seven damage categories (see Table 1), whereas the Ahmedabad damage data was categorized into six (see Table 3). The damage states 2 and 3 considered by the ATC methodology have been combined, and are assumed equivalent to the G1 category of the Ahmedabad damage categorization.

The DPMs calculated using the ATC methodology for the moment resisting non-ductile frame buildings subjected to shaking intensity of VII and VIII on the MMI scale are presented in Table 5. Also presented in the table is the Ahmedabad data (categorized by the height of the building). Further, for all Ahmedabad buildings (regardless of height), comparison with ATC 13 numbers for mid-rise buildings subjected to intensity VII and VIII is presented in Fig. 1. More details on the Ahmedabad data are available in [6].

Table 5 – Distribution of buildings in various damage states given by DPMs in ATC 13 and in Ahmedabad during the 2001 Bhuj earthquake

Damage state	Low-rise			Mid-rise			High-rise		
	ATC		Ahme-dabad	ATC		Ahme-dabad	ATC		Ahme-dabad
	VII	VIII		VII	VIII		VII	VIII	
G0	0	0	9.9	0	0	6.6	0	0	2.7
G1	99	37.5	52.5	97.2	33.6	49.4	91.5	32.2	50.4
G2	1	62.3	31.6	2.8	65.7	35.4	8.5	66.9	41.2
G3	0	0.2	5.5	0	0.7	8.0	0	0.9	5.4
G4	0	0	0.3	0	0	0.5	0	0	0
G5	0	0	0.2	0	0	0.1	0	0	0.4

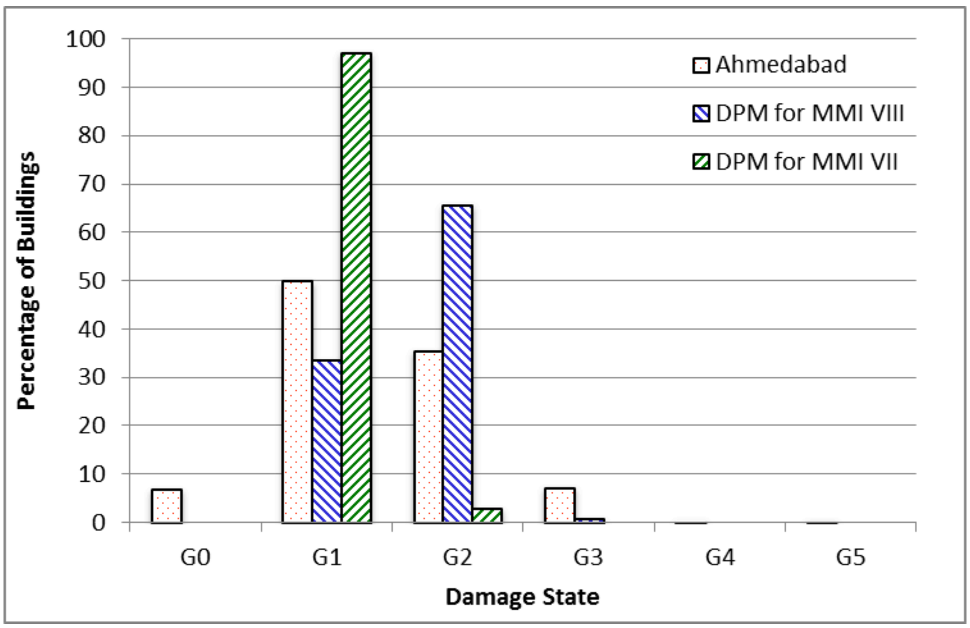

Fig. 1 – Comparison of observed damage data of all RC frame buildings in Ahmedabad (irrespective of story height) with the prediction made by ATC 13 for mid-rise buildings for intensity VII and VIII

It can be seen that the ATC-13 estimates for MMI VII are not close to the distribution obtained from Ahmedabad data. ATC-13 criteria is predicting 90-99% buildings in G1 and 1-10% buildings in G2, while Ahmedabad data shows 49-53% buildings in G1 and 30-36% in G2. Hence, the ATC-13 prediction for MMI VII clearly underestimates the damage for Ahmedabad buildings.

The ATC-13 predictions for MMI VIII provide a somewhat better match with damage data from Ahmedabad. As per ATC-13, 30-40% buildings are in G1 and 60-70% buildings are in G2, while Ahmedabad data shows 49-52% buildings in G1, and 30-36% in G2. It may appear that ATC-13 predictions corresponding to MMI VIII overestimates the damage for Ahmedabad buildings. However, one may note that ATC-13 predicts very few (0.2-0.9%) buildings in G3 under MMI VIII, while Ahmedabad data shows 5-8% buildings in this damage state. Further, ATC-13 has no buildings in G4 and G5, while Ahmedabad data observes up to 0.5% buildings in G4, and up to 0.47% buildings in G5.

It is therefore seen that ATC-13 values of DPM for intensity VIII are closest to the experienced data of Ahmedabad under shaking intensity VII. That is, when applying DPM values of ATC-13 to Ahmedabad buildings, the intensity should be shifted up by one level to account for lower quality of constructions in Ahmedabad. This may provide a reasonable estimate of financial loss in Ahmedabad but will significantly underestimate the deaths and injuries. This is because, even with shifting up by one level, the ATC-13 highly underestimates the number of buildings that will go into G4 (severe structural damage) and G5 (collapse).

4. Summary and conclusions

Damage data of about 3,000 buildings in Ahmedabad during the 2001 Bhuj earthquake has been studied in the context of ATC 13 recommendations for non-ductile RC frames. The city experienced a shaking intensity of VII on the MMI scale during the earthquake.

The damage in Ahmedabad was significantly higher than the damage estimated using the ATC methodology for a shaking intensity of VII for non-ductile buildings. A relatively better match between the observed damage and the ATC estimate is achieved when the shaking intensity of one unit higher (i.e., VIII on MMI scale) is used to calculate the percentages as per ATC. Even after the increasing the shaking intensity for the calculation using the ATC methodology, the severe structural damage and collapse are under estimated.

The construction industry in Ahmedabad has learnt from the 2001 earthquake and the contemporary constructions are somewhat better even though concerns on quality remain. However, the results do indicate the vulnerability of typical multistory residential apartments in urban India.

Developing countries, such as India, tend to have poor checks and balances for ensuring quality of design and construction. This makes their building stock more vulnerable. However, it is seen that as compared to ATC recommendations, not only one gets higher vulnerability of buildings on the average, but there is also a significantly larger spread in the vulnerability. That is, a significantly larger percentage of buildings are prone to collapse (and hence may lead to much larger number of deaths) than what may be indicated by the ATC method even with increase in shaking intensity by one unit.

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6. Copyrights

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