KASHMIR EARTHQUAKE OF OCTOBER 8, 2005: FIELD OBSERVATIONS AND STUDY OF CURRENT SEISMIC PROVISIONS FOR BUILDINGS IN PAKISTAN

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ABSTRACT :

On the morning of the 8th October 2005 a Magnitude 7.6 earthquake occurred in Pakistan at the foothills of the Himalayas. Over 80,000 people were killed in the event. The violent ground shaking triggered many land slides and caused damage to more than 450,000 buildings. Following the event, the authors participated in the Earthquake Engineering Field Investigation Team (EEFIT, part of the UK Institution of Structural Engineers) field mission. The authors spent 10 days in the field surveying the damage to buildings and lifelines in North Western Frontier Province and Pakistan Administered Kashmir. This paper first presents observations of physical damage to reinforced concrete and masonry buildings observed by the authors in Pakistan. A study of the current seismic design provisions for Pakistan is also presented together with a critical assessment of the seismic hazard maps for Pakistan. Comparisons are made with provisions in the US and Europe and recommendations made for the future improvement of the Pakistan seismic code.

KEYWORDS: Pakistan, Kashmir Earthquake, Pakistan Seismic Code

1. INTRODUCTION

On the morning of the 8th October 2005 a Magnitude 7.6 (M_w) earthquake occurred in Pakistan at the foothills of the Himalayas. It caused widespread destruction in Azad Jammu Kashmir (AJK) and in the eastern districts of North West Frontier Province (NWFP). In Pakistan alone 72,763 people died and 68,679 were injured, (January, 1 2006). In total the violent ground shaking caused damage to more than 450,000 buildings, leaving about 2.8million people without shelter. The heaviest damage occurred to cities of Muzaffarabad and Balakot that were nearest to the fault rupture responsible for the earthquake. Ground shaking was felt as far south as Islamabad, resulting in one spectacular building collapse. Heavy damage was also reported from the Indian side of Kashmir. The worst affected towns were Tangadhar in Kupwara district and Uri in Baramula district where about 80% of the town was destroyed. Furthermore, the ground shaking caused numerous landslides and rockfalls to be triggered that damaged roads and bridges, blocking access to heavily damaged areas and hampering the relief effort. The total losses to public and private assets amount to US$2.3 billion, with an overall cost of US$5.2 billion including recovery needs. Following the event, the authors participated in the Earthquake Engineering Field Investigation Team (EEFIT) field mission. The authors spent 10 days in the field surveying the damage to buildings and lifelines in North Western Frontier Province and Pakistan Administered Kashmir. This paper starts with a description of the earthquake, and then presents the observations of damage to buildings observed by the authors in Pakistan. Finally, studies of the current seismic design provisions and seismic hazard maps for Pakistan are presented and discussed, and recommendations for their future improvement are made.

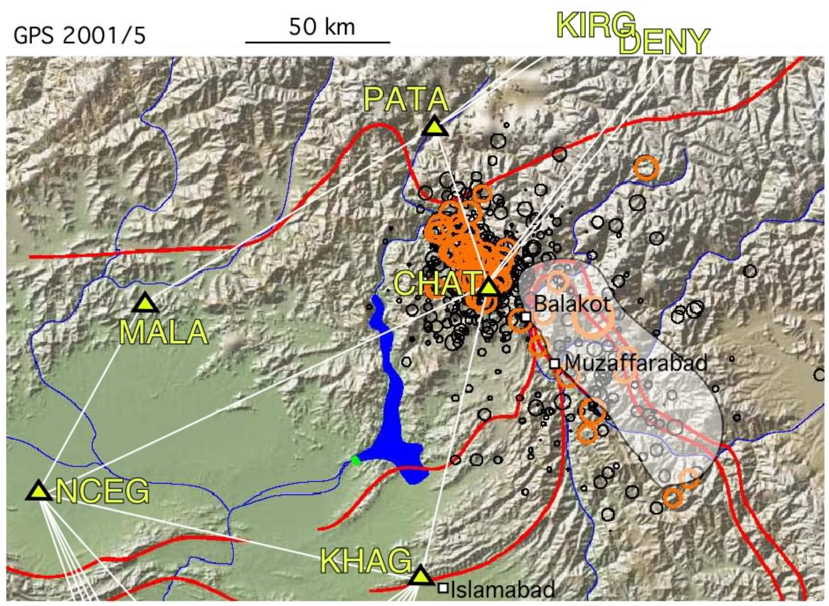

Figure 1: Earthquake location and aftershocks from USGS, and the inferred rupture zone of 90km x 40km (after Bilham, 2005).

2. THE EARTHQUAKE

The October 8, 2005 Kashmir Earthquake occurred at 03:50:40 UTC (08:50:40 am local time). Its epicenter was located at 34.493°N and 73.629°E, about 10km Northeast of Muzaffarabad and 105km North-Northeast of Islamabad (USGS). The earthquake had moment magnitude 7.6 (Mw) and focal depth of 26km (USGS). The causative fault of the main shock was located by COMET (2005) using readings of ground displacements made using radar amplitude measurements from satellites. The fault strike lies in the N27E to N30E direction and the average slip was estimated to be between 2-4m. Bilham (2005) describes the inferred rupture to cover an area of 90km x 40km on the Indus-Kohistan Seismic Zone (shaded in Figure 1) with a 37º dip in the NE direction. The fault segment on the Indus-Kohistan Seismic Zone that was responsible for the October 8, 2005 Kashmir Earthquake is thought to be the reactivated Muzaffarabad fault, which is a thrust (reverse) fault. Strong motion recordings for the Kashmir Earthquake were available in Abbottabad, Murree and Nilore, located at 48km, 64km and 100km from the epicenter, respectively. These show horizontal peak ground acceleration values of 0.231g, 0.078g and 0.023g, respectively (Chaudury, 2005). They also have comparatively high vertical components, measuring 0.087g, 0.069g and 0.03g, respectively. Durrani et al. (2005) used the attenuation relationship of Ambraseys and Douglas (2005), which was found to model well the ground motions recorded in Abbottabad, Murree and Nilore, to suggest a PGA of 0.7g and 0.9g for stiff and soft soil sites in Muzaffarabad, respectively. These values will be referred to when looking at seismic hazard maps for Pakistan.

3. OBSERVED BUILDING DAMAGE

The Kashmir Earthquake destroyed over 270,000 buildings and partially damaged about 180,000 buildings in the districts of North West Frontier Province (NWFP) and the Pakistan administered Kashmir (AJK). Buildings in these regions can be broadly divided into four construction classes: unreinforced stone, concrete block and brick masonry, and reinforced concrete moment-resisting frames. A full description of the performance of the construction techniques, materials and earthquake performance of these structural types are described in Rossetto and Peiris (2008). A summary of the performance levels assigned to these buildings according to occupancy class and using FEMA 356, is given in Table 1. This table demonstrates the poor performance of both engineered (largely RC structures) and non-engineered (URM and some low rise RC) structures. Which raises the question of whether the Pakistan seismic code was followed in the engineered buildings, and whether it is adequate for reconstruction.

Table 1. Observed Pakistan building performance by occupancy class using FEMA 356

Occupancy	Dominant Construction Class	Performance Level
Residential	Unreinforced masonry (URM)	Collapse prevention or worse
Commercial	Uneinforced masonry (URM)	Collapse prevention or worse
	Reinforce concrete (RC)	Immediate occupancy or life safety
Government Administration	Uneinforced masonry (URM)	Life safety or collapse prevention
Schools	Uneinforced masonry (URM)	Collapse prevention or worse

4. THE PAKISTAN CODE SEIMIC LOADING PRESCRIPTIONS

The Pakistan seismic code was published in October 1986 and quoting the document is “an advisory document for use throughout Pakistan with a view to achieve uniform objectives…” and “legal enactment are expected to be sought under various laws of the land framed for the purpose of building activities”. This suggests that the seismic code was never enforced in the Kashmir region of Pakistan. This section gives a quick review of the Pakistan code seismic loading prescriptions as these represent the current level of national seismic design guidance available to the Pakistan building industry for reconstruction. The static lateral force procedure for seismic load calculation is first summarized. The resulting base shears are compared to prescriptions in Eurocode (EC) 8 and Uniform Building Code (UBC) 1997 for similar seismic hazards and building types. Finally the seismic hazard map for Pakistan is analysed and discussed on its adequacy.

4.1 Summary of the Pakistan Seismic Code Static Lateral Load (Base Shear) Calculation

The Pakistan seismic code defines a static lateral force procedure for determining the seismic actions on buildings (these actions do not apply to nuclear power stations, dams and other important structures). The design base shear (*V*) is given by Eqn 4.1:

$$V = ZIKCSW \quad \text{and} \quad CS \leq 0.14 \tag{4.1}$$

Where *Z* is the zone factor, *I* is the occupancy importance factor, *K* is the horizontal force factor, *C* is the base shear coefficient, *S* is a numerical coefficient for site-structure resonance and *W* is the total dead load. *Z* is determined from the seismic zoning map of Pakistan presented in the code. The values of *Z* for each zone are presented in Table 2. These do not represent the peak ground acceleration associated with the zones. The value of *I* is given by the code to equal 1.5, 1.25 and 1.0 for essential facilities, facilities assembling more than 300 people and all other structures, respectively. Essential facilities are defined by the Pakistan code as hospitals, fire and police stations. This category therefore does NOT include schools, which were a major cause of life loss during the Kashmir earthquake. *K* is defined based on the arrangement of structural resisting elements, and takes a value of 0.8 for dual bracing systems, 0.67 for ductile moment resisting frames and 1.0 for all other frame building systems. The base shear coefficient, *C*, is determined similarly to Uniform Building Code (UBC) 1997 as:

$$C = \frac{1}{15\sqrt{T}} \quad \text{where} \quad T = \frac{0.05h_n}{\sqrt{D}} \quad \text{and} \quad C \leq 0.12 \tag{4.2}$$

Where *T* is the fundamental period of vibration of the structure, h_n is the height of the building above ground level and *D* is the length of the building plan in the direction of applied load. Both h_n and *D* are measured in metres. An alternative equation (*T = 0.1N*, where *N* is the number of stories in a building) is also proposed for calculating the fundamental period in ductile moment resisting frames. *S*, the numerical coefficient for site-structure resonance, must always be greater than or equal to 1.0, and is evaluated from the following equations relating *S* to the ratio of structure to characteristic site period (T/T_s):

$$\text{For } T/T_s \leq 1.0 \quad S = 1.0 + \frac{T}{T_s} - 0.5\left(\frac{T}{T_s}\right)^2 \tag{4.3}$$

$$\text{For } T/T_s > 1.0 \quad S = 1.2 + 0.6\frac{T}{T_s} - 0.3\left(\frac{T}{T_s}\right)^2 \tag{4.4}$$

Where *T* is to be established by a properly substantiated analysis but shall not take a value less than 0.3s. If *T* has been established from a properly substantiated analysis but exceeds 2.5s, the value of *S* is found by assuming T_s = 2.5s. When instead T_s is not properly established then a value of *S* of 1.5 should be taken.

4.2 Comparison of Base Shear Prediction in Pakistan Seismic Code with Eurocode 8 and UBC 1997

In order to compare the Pakistan Code seismic loading provisions with those of other regions the levels of seismic hazard specified by the Code for different regions in Pakistan need to be determined. A problem with the Pakistan Seismic Code is that the zone factors, *Z*, associated with each area do not directly represent the value of PGA being designed for. This makes it difficult for the engineer to compare the seismic provisions with those implemented in locations with similar tectonic settings and seismic activity. A back-analysis of the normalized base shear (V/W, that is representative of the spectral acceleration response) equations of the 1986 code was therefore carried out in order to find the PGA values implied by the zone factors. This back-analysis consists of plotting the variation in V/W with T given by the Pakistan Seismic Code for the different zones and matching the constant plateaus with those of similar plots derived from Eurocode 8 (EC8) (see Figure 2). The comparison, carried out for ordinary importance (I = 1, γ_I = 1), ductile and non-ductile moment resisting frames (K = 0.67 and 1.0, q = 5.4 and 3.6), for rock and soft soil site conditions (T_s = 0.08s and 0.67s, Soil class A and D). All the plot comparisons concur to give the values of PGA shown in Table 2.

Table 2. PGA values for the Pakistan seismic zones derived from comparison with Eurocode 8 and those stated in the new seismic zone map of Pakistan

Zone (1986 code)	Z-value	PGA (g) EC8	Zone (2005 map)	PGA (g) (2005 map)
0	3/32	0.016	1	≤ 0.03
1	3/16	0.033	2	0.03 – 0.1
2	3/8	0.065	3	0.1 – 0.3
3	3/4*	0.130	4	≥ 0.3

* *In locations in Zone 3 that are near known faults Z should be taken to equal 1*

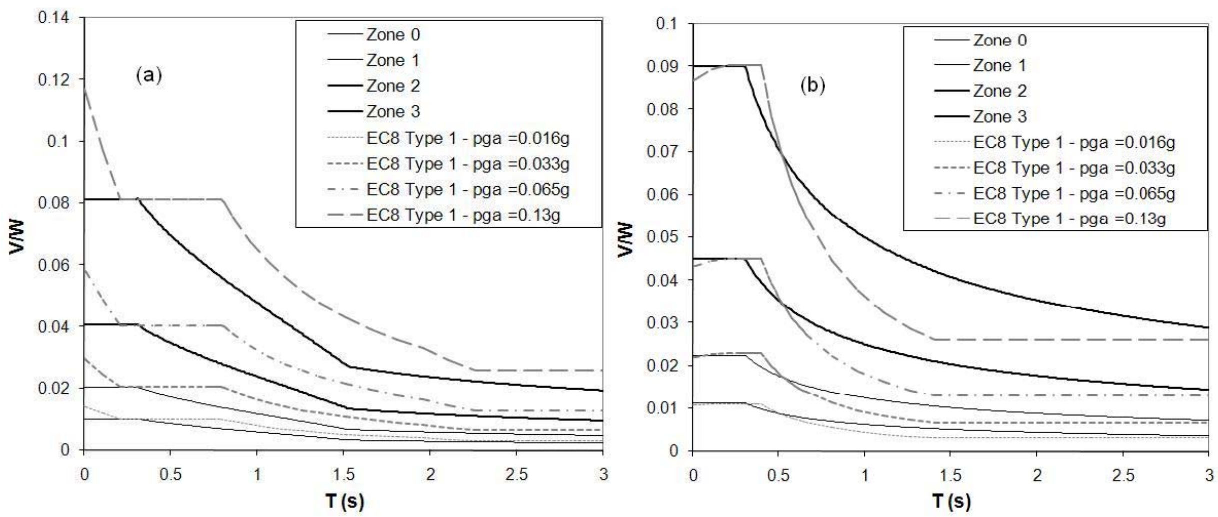

Figure 2: Examples of the plots of normalized base shear vs building fundamental period given by the Pakistan 1986 Seismic Code and Eurocode 8 (EC8) used to find the PGA corresponding to each seismic zone: (a) Normal importance, ductile frame and soil conditions, (b) Normal importance, non-ductile frame and rock-site conditions.

Figure 2 shows that for soil site conditions EC8 assigns a greater base shear than the Pakistan Seismic Code for structures with fundamental periods between 0.6s to 2.0s. The opposite is true in the case of the rock site, although the difference is not as large in this case. This would seem to suggest that the 1986 Pakistan Seismic code under-predicts the seismic actions on flexible structures. A similar trend is seen in the comparison between the Pakistan code and UBC 1997 in Figure 3. In the latter it is clear that the base shear prescribed by the 1986 Pakistan seismic code for the design of buildings in its highest zone, is often less than that prescribed by UBC 1997 for its second lowest seismic zone (Zone 2A). The base shear given for Zone 2 in the Pakistan seismic code, which applies to the Kashmir Region, is in most cases seen to be less than that for Zone 1 in UBC 1997. The difference in magnitude of the prescriptions for base shear is further illustrated in Table 3.

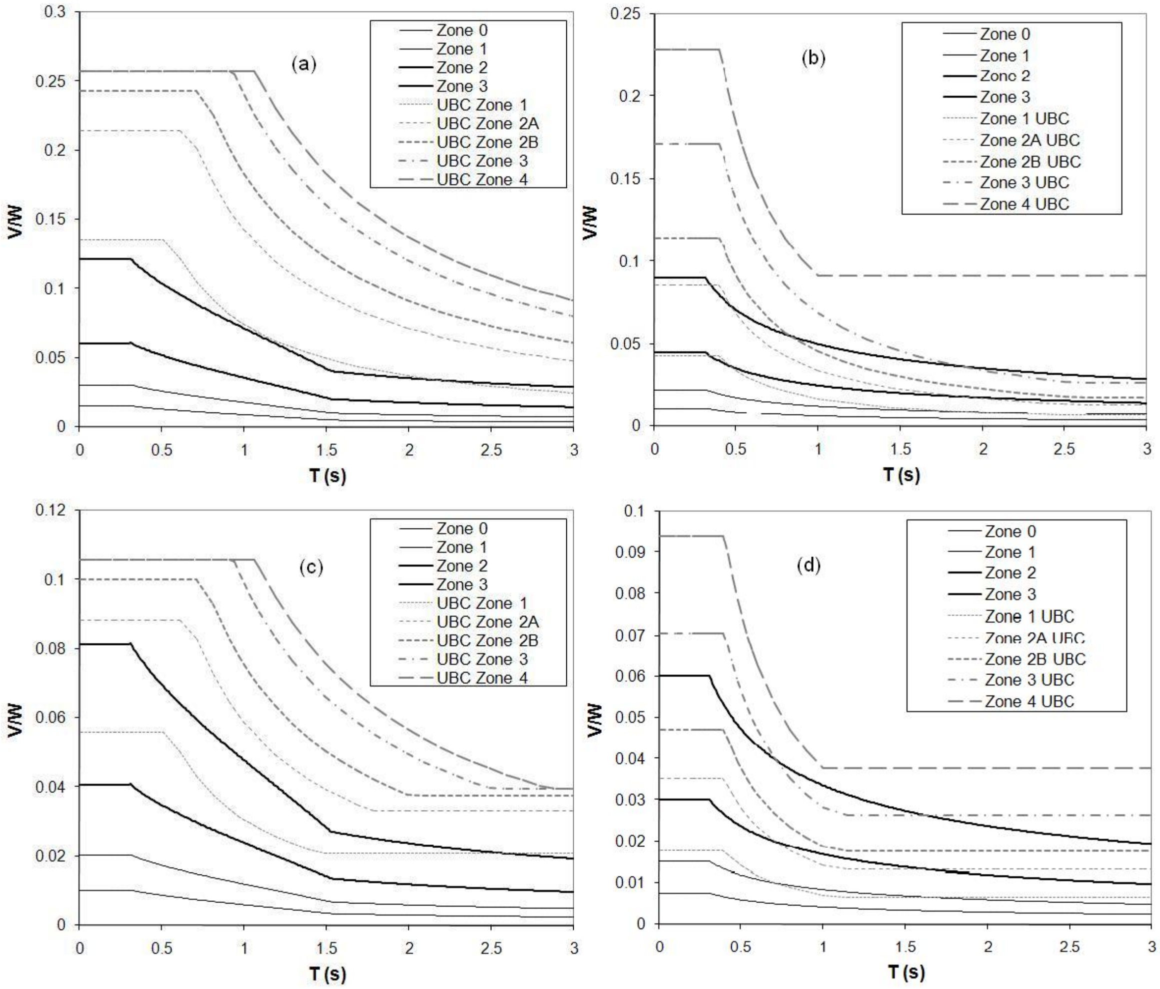

Figure 3: Examples of the plots of normalized base shear vs building fundamental period given by the Pakistan 1986 Seismic code and UBC 1997: (a) Normal importance, non-ductile MRF and soft-soil site conditions, (b) Normal importance, non-ductile MRF and rock site conditions, (c) Normal importance, ductile MRF and soft-soil site conditions, (d) Normal importance, ductile MRF and rock site conditions.

Table 3. Normalised base shear (V/W) values for 3- and 5-strorey ductile and non-ductile RC MRFs founded on soft soil and rock sites, calculated according to UBC 1997 and the 1986 Pakistan Seismic Code.

Building Type	Soft Soil			Rock		
	PK 86 Zone 2	UBC 97 Zone 1	UBC 97 Zone 4	PK 86 Zone 2	UBC 97 Zone 1	UBC 97 Zone 4
3-storey non-ductile MRF	0.061	0.136	0.257	0.045	0.043	0.229
3-storey ductile MRF	0.061	0.133	0.257	0.045	0.031	0.164
5-storey non-ductile MRF	0.040	0.056	0.106	0.030	0.018	0.094
5-storey ductile MRF	0.035	0.055	0.106	0.024	0.013	0.068

The above comparisons have several implications for the performance of buildings during earthquakes in the Kashmir region. Firstly, the lower levels of spectral accelerations in the Pakistan seismic code suggests that even if the buildings are designed to the code level, they may not have performed at their expected level of life-safety for ground motions comparable to the design level. The reason is that the design spectral accelerations are such that the buildings' design capacities would be insufficient. Secondly the inconsistencies in the zonation and PGA relationship suggest that the ground motion level in the design code may not reflect the uniformity of risk required in defining the base shear. The Kashmir region has many faults in proximity to population centers. The re-activated Muzaffarabad fault responsible for the Kashmir Earthquake is located within about 10km from cities of Muzaffarabad and Balakot. These cities may have experienced the near source effects of ground motions, reflected in the extent of building collapses seen during the ground observations. Such near source effects are not explicitly considered in design base shear calculation by the Pakistan seismic code except for the moderate adjustment to the zone factor. The ground motion record in Abbottabad about 48km from the epicenter showed higher energy content in the spectral period range from 0.4s to 2.0s (Durrani et al., 2005). The ductility modified spectra also showed average strength demands from structures of intermediate ductility (ductility of around 2.0). This has implications for the multi-storey RC structure performance in the region, which is not reflected in the building code.

4.3 Discussion of the Pakistan Seismic Code Zoning Map

The above comparison clearly raises concerns regarding the adequacy of the Pakistan Seismic Code Zoning map. The 1986 code provides a seismic zoning map that divides Pakistan into four zones, (see Table 7). The zonation is based on instrumental data collected from the Quetta Geophysical Centre between 1905 and 1979, and from values of felt intensity in each region during past earthquakes. Quoting the code: "the maps are based on a simple premise that the ground motion of a certain intensity experienced once in a certain area is likely to experience again in that area", and "the map does not take into account recurrence intervals of different magnitude earthquakes". These are serious assumptions which severely affect the usefulness of the code.

Table 4. Summary of the seismic zones defined in the Pakistan Seismic Code

Zone	Description of likely intensity	Z-value
0	Negligible damage MMI[*] $\leq$ IV	3/32
1	Minor damage. Distant earthquakes may cause damage to structures with T > 1s. MMI = V to VI.	3/16
2	Moderate damage. Corresponds to MMI = VII	3/8
3	Major damage. MMI $\geq$ VII	3/4[4]

[*] *Modified Mercalli Intensity of 1931;*[**] *In locations in Zone 3 that are near known faults Z = 1.*

All the areas in Azad Jammu Kashmir (AJK) and North West Frontier Province (NWFP) that were affected by the October 8, 2005 earthquake lie in Seismic Zone 2. According to Table 4, these areas are likely to be subjected to moderate damage, corresponding to Intensity VII. In fact the affected areas i.e. Balakot, Muzaffarabad, etc. were observed to have Intensities ranging from VIII to X, which greatly exceed that defined for Zone 2. Hence in a seismic zone map such as this, where the zone is determined based on observed intensity in prior earthquakes, the epicentral region should be assigned to Zone 3 (as defined in Table 4). The statement made that in drawing the maps, "the recurrence intervals of different magnitude earthquakes were neglected", means that a probabilistic seismic hazard analysis was not used in delineating the seismic zones. Hence, the zone factor (which represents the ground motion) in each location is associated with a different (and non-quantified) exceedence probability. This means that structures in different locations are being designed for different for different (and unknown) levels of risk. This is a serious problem for engineers using the Pakistan Code.

Following the October 8, 2005 event a new version of the Pakistan seismic hazard map was released by the

Geological Survey of Pakistan. A significant change can be observed in the contours of the zones which arise from the inclusion of historical records (large events dating back to the 17th century are recorded on the map). One obvious difference is that the area around Muzaffarabad has been assigned to the highest zone. Furthermore, all zones have been upgraded and Seismic Zone 0 has been eliminated, even though the descriptions of the zones in terms of intensity are virtually unchanged. In this map, ranges of PGA are presented for each seismic zone. Although the new map may be an improvement on the old seismic zone map in terms of the additional earthquake data used, it also neglects the recurrence intervals of different magnitude earthquakes. The PGA values are therefore most likely extrapolated from strong ground motion, either recorded or derived from ground motion prediction equations, for large events in the past. Thus it poses the same problem to engineers of non-uniform and unknown seismic risk for their structure designs. The values of PGA presented in the new version of the Pakistan zoning map are however seen to be significantly higher than those implied by the old code zone factors. This means that designs carried out following the 1986 code may be unsafe in view of the new "improved" hazard assessment. GSHAP assigns PGA values to the Kashmir region in Pakistan ranging between 0.24g to 0.32g, with some areas in the NWFP being in the range 0.32g to 0.4g. These values tie in fairly well with the new seismic zoning map for Pakistan, but are three times larger than the PGA values assigned to the area by the old zoning map.

5. CONCLUSIONS

The static lateral force procedure presented in the 1986 Pakistan Seismic Code is not an unreasonable basis on which to build a new seismic code for Pakistan. However, a revision of the Pakistan seismic code should be made to include capacity design principles and modern developments in terms of seismic analysis and design. Major flaws have however been identified in the seismic zone map, which needs to be revised to include both recent and historical seismic events and a probabilistic seismic hazard evaluation.

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