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Microzonation Studies for Delhi, Jabalpur & Dehradun as Impacted by Bhuj Earthquake

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ABSTRACT

History of earthquakes in our country demonstrate vulnerability to seismic hazards. The recent past, devastating earthquakes in urban areas in India causing heavy economical losses in terms of loss of life, property, disruption of services and damage to environment have been of great concern; the experiences have prompted to carry out in-depth studies and come out with solutions and policies which will go a long way in minimizing the damages caused by seismic ground motions. In this context, microzonation of urban areas have assumed new dimensions.

Delhi, the capital city of India has a long seismic history and is being affected by local as well as by the Himalayan earthquakes. The Jabalpur urban agglomeration lies in the field of recurrent seismicity ascribed to the reverse activation of Son-Narmada South Fault. Dehradun, the capital city of Uttaranchal is located in the foot hills of Himalayas and is sitting on a tectonically isolated block confined between main boundary thrust & Himalayan Frontal Thrust. Macroseismic surveys of the earthquake effects have unraveled site-dependent ground amplifications increasing the vulnerability of the built environment to seismic hazards. Hence, a need is felt to carry out prognostic damage scenario of existing building stocks in urban area, review the existing codal provision of buildings so that appropriate disaster mitigation measures can be evolved. Keeping this in view, CBRI, Roorkee (India) has carried out studies to generate inputs on vulnerability of engineered and non-engineered structures and anthropic parameters of population living in dwelling susceptible to damage and other exposure factors for fourth level seismic risk microzonation with engineering seismological perspective. The paper briefly describes the microzonation studies initiated in India for Delhi, the capital city of India, Jabalpur & Dehradun, the capital of newly formed Indian state, Uttaranchal. The paper presents two approaches namely Demand Capacity Ratio (DCR) approach & Rapid Screening Procedure(RSP) for assessment of seismic vulnerability of existing building stocks.

INTRODUCTION

Experiences of earthquakes in last decades in semi-urban & urban parts of India [Uttarkashi (1991); Latur (1993); Jabalpur (1997); Chamoli (1999); & Bhuj (2001)] have caused deep concern with regards to seismic hazards and resulting risk. In this context, not only the well known seismic belts of Himalayan-Nagalushai region, Indo-Gangetic Plain, Western India, Kachchh and Kathiawar regions in geologically unstable parts of the country, where most devastating earthquakes of the world have been witnessed, but also other seismic zones where events such as Latur (M6.3, 1993) and Jabalpur (M6.0, 1997) earthquakes have wreaked devastation in recent past, are of equal concern. The damages in huge proportions to the engineered and non-engineered structures during Bhuj earthquake have shown that not only the source ground characteristics but also the vulnerability of the built environment render the domain susceptible to earthquake hazards.

The rapid industrial growth, population explosion and consequent escalation of urbanization with accelerated pressure on housing industry, have caused increasing vulnerability of built environment to earthquakes. The interest of social and economic stability requires recognition of earthquake risk, commitment & preparedness to encounter the hazard and their mitigation.

The seismic hazard & risk microzonation (SHRM) offers an effective tool to generate inputs for hazard mitigation planning. In order to evolve an expert system of SHRM, at the behest of Govt. of India, Department of Science & Technology, New Delhi, a multi-disciplinary & multi-institutional experiment on microzonation has been conducted. Jabalpur was in meizoseismal area of 1997 earthquake. Hence, keeping in view, the recent seismic activity and the historical - cultural - industrial - strategic importance of the town, the Jabalpur has been identified as model for microzonation studies.

A deterministic approach to hazard and risk analysis (DHRA) has been resorted and based on the experiences of preliminary studies on microzonation, a conceptual model for SHRM has been evolved (Mishra, P.S. et al, 2001; Agrawal et al, 2003) . It envisages four level microzonation viz. (a) base or 1st level geoscientific microzonation, (b) microzonation with geotechnical inputs on ground characterization, (c) microzonation improvised with parameters on site effect and ground response, and (d) *seismic risk microzonation with engineering seismological inputs on vulnerability of engineered and non-engineered structures and anthropic parameters of population living in dwelling susceptible to damage and other exposure factors*. The paper presents seismic vulnerability of existing building stock for seismic risk assessment; the results will be collated with the microzonation maps. In addition the microzonation related studies going on for Capital city of India i.e. Delhi and Dehradun, a capital of newly formed state, Uttaranchal are also presented in the paper. The seismic vulnerability is a measure of the seismic strength or capacity of a structure, hence it is found to be the main component of seismic risk assessment and microzonation thereof.

SEISMIC MICROZONATION STUDIES IN DELHI

Delhi, presently the metropolitan and capital city of India is a centre of attraction since historical times. Delhi has remained India's capital for nearly ten centuries bearing stamps of successive rulers- Hindu, Pathan, Mughal, Mauryan and British. The city of Delhi is located at the northern end of Aravali mountains and is surrounded by Gangetic alluvium from almost all sides. The Delhi region is having several small tectonic features, which have been rocking it with minor and major earthquakes since historical times. Qutab Minar's cracks(on its wall) are proof of these past earthquakes. In this regard several authors often mention 1720 earthquake of intensity VIII-IX and the 1803 earthquake of intensity VIII from this region. It has been highlighted time and again that Delhi might face an earthquake of magnitude, 7 in future based on past history of earthquake and the geotechnical setting in the background (Tandon & Chaudhury, 1966, Srivastava & Somayajulu, 1966). In the eventuality, the most severely affected area will be around the banks of river Yamuna.

The Delhi region has a long seismic history, being affected by local earthquakes, as well as by the Himalayan earthquakes. The first reliably recorded earthquake of Delhi was on 15 July 1720. From eyewitness accounts, the MM intensity in the felt area (old Delhi) can be estimated **as IX.** During recent times, the most significant was the shock of 27 August 1960 (M=6.0) having its epicentral tract between Delhi and Gurgaon. As per field survey (Srivastava and Somayajulu, 1966) some 76% of the constructions in the epicentral region suffered damage to varying degrees. On 28 July 1994, an event of magnitude 4.0 was reported to have caused damage to one of the minarets of the historical Jumma Masjid. Places neighboring Delhi have also experienced several earthquakes. Near Mathura a strong earthquake (MMI=IX) occurred on 1 Sept. 1803, causing fissures in the ground.

After experiencing the effect of recent Chamoli earthquake of 29th March 1999 in some parts of Delhi (the cracks developed in some multistoried buildings in Trans Yamuna area), there is a heightened level of awareness amongst the public to natural disasters in urban areas. Delhi, being the socio-political and economic nerve centre of the country, demands much more attention from architects, planners, engineers and decision-makers towards disaster preparedness.

Delhi Strong Motion Accelerograph (DSMA) Network was established in Delhi region by Central Building Research Institute, Roorkee, in the year 1996, to collect the strong motion data in the region. The network consists of 16 strong motion stations to cover the region within a radius of 200 km. Out of these 16 instruments, 8 instruments are deployed in Delhi and remaining 8 stations are located outside Delhi city. At each station a triaxial digital strong motion accelerograph (Altus K2, Kinemetrics, USA) is deployed to record the acceleration time history of ground motion in digital form at a sampling rate of 200 samples/sec. Till date 20 earthquakes have been recorded on DSMA network. These include 12 distant events and 8 local events. The location details of these instruments are shown in ***Fig. 1.***

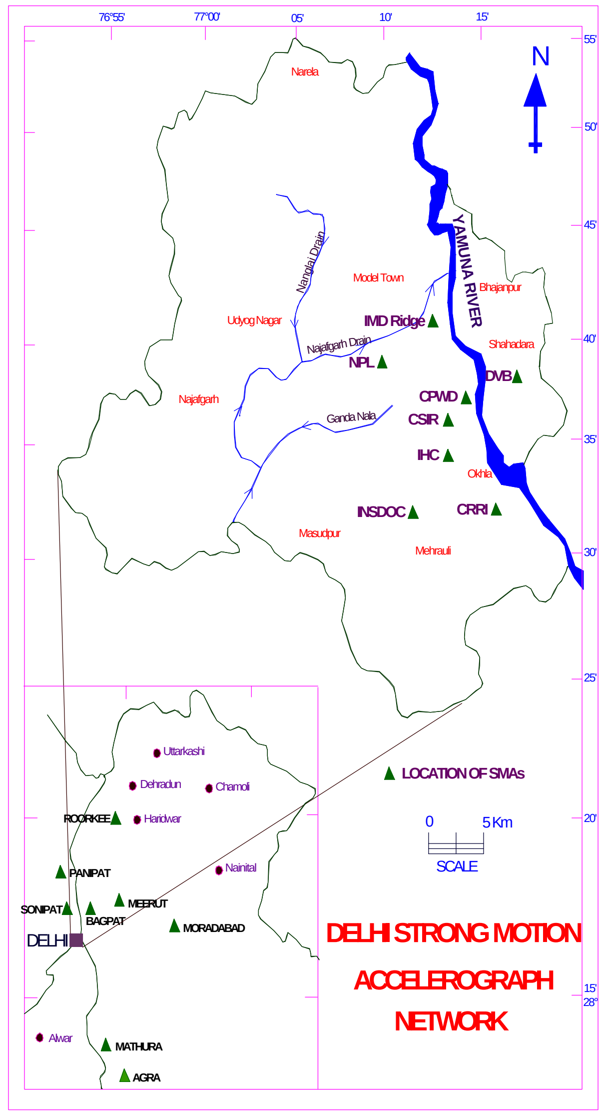

Fig. 1. Location of DSMA Network in and around Delhi region

An attempt has been made to use the real earthquake strong motion data recorded by DSMA Network for site response study. The data used in the study is of seven earthquakes, which, took place in different directions and were recorded at CSIR (Rafi Marg), IHC (Lodi Road), IMD Ridge Observatory (North Campus Delhi Univ.), CPWD (near ITO) and CPCB (Arjun Nagar). The analysis of the data has shown clear-cut difference in natural frequency for these stations. These stations have different site conditions i.e. CPWD area has thick alluvial cover while the other have thin soil cover as compared to the CPWD. The IMD site is true hard rock site. The values for natural frequencies on these stations for real earthquakes are shown in *Fig. 2.*

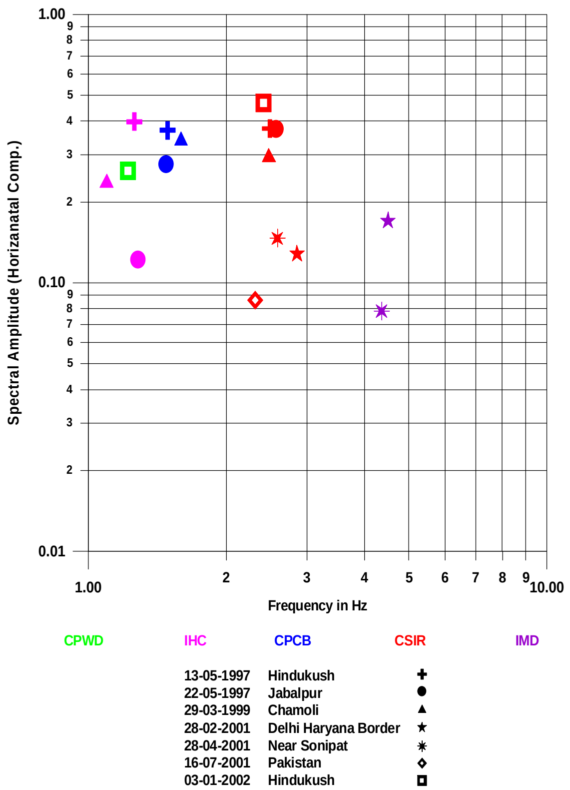

Fig. 2. Natural frequency map at different sites in Delhi

Ambient Noise Data Analysis

Site response studies on the basis of micro tremor or ambient noise data are one of the well-known tools of seismic hazard assessment. The basic principle behind this study is that each site has its own natural frequency depending upon the thickness of soil layer, geological structure and its age, type of soil below the ground and ground water level at the site. On the other hand, every structure has its own natural frequency, which depends upon its shape, size, type and material used etc. Ambient noise studies enable us to know the dominant frequency of the ground at a particular site, and any structure having the same natural frequency may experience amplified and violent shaking in case of an earthquake due to resonance phenomenon. It is, therefore, necessary to carry out site response study to determine safer areas for construction of buildings, bridges, flyovers and other structures.

Large number of instrumental data was collected from different areas of Delhi and the same was analysed with the help of non-reference site dependent spectral ratio technique suggested by Nakamura (1989). This technique is known as the horizontal to vertical spectral ratio (HVSR). The basic assumption is that the local site conditions do not significantly influence the vertical component of the ground motion. Thus, site response could be estimated by deconvolving the vertical component from the horizontal one. Several studies indicate that HVSR for S - wave, but not for P–wave, establishes the overall frequency dependence of site response.

JABALPUR

The study comprises review of the existing buildings of Jabalpur in the light of guidelines for earthquake resistant construction in India, behaviour of buildings during 1997 earthquake, construction practices being adopted in Jabalpur urban area (pre & post earthquake), building typology, designing of questionnaire for detailed survey of buildings, zoning of the Jabalpur urban area, selection of representative building samples, detailed survey of selected buildings, and creation of database. Subsequently, seismic vulnerability of existing building stock has been estimated quantitatively and qualitatively. The quantitative approach covers demand-capacity computation, while qualitative procedure estimates structural scores based on national & international state-of-the-art procedures viz. Rapid Screening Procedure (RSP). The interpretation/output of response of different types buildings (zonewise) during future earthquake in Jabalpur urban area are mapped and collated using Arch Info and GIS in query-mode, compatible for planning of pre-disaster mitigation measures.

Existing Building Scenario in Jabalpur Urban Area

India has a very complex socio-cultural environment and its built environment encompasses the widest possible range from non-engineered dwellings built with traditional skills to the most modern buildings, and Jabalpur is no exception. The Jabalpur urban area is spread over 290 sq. km., while Jabalpur district comprising around 6.2 lakhs dwellings of different typology (Table-1).

Table-1 : Distributuion of Houses by Predominant Materials of Roof/Wall*

Wall & Roof Combination		**Census Houses**	
		No. of Houses	**%**
Type-A	Urban	74,825	20.75
	Rural	2,85,650	79.25
	Total	***3,60,475***	***58.42***
Type-B	Urban	1,82,655	79.50
	Rural	47,115	20.50
	Total	2,29,770	**37.24**
Type-C	Urban	9,405	84.10
	Rural	1,775	15.90
	Total	***11,180***	***1.81***
Type-X	Urban	9,480	60.75
	Rural	6,125	39.25
	Total	***15,605***	***2.53***
Grand Total		**6,17,030**	

Building Category

Type-A: Buildings in field-stone, rural structures, unburnt brick houses, clay houses

Type-B: Ordinary brick buildings, buildings of the large block and prefabricated type, half-timbered structures, building in natural hewn stone

Type-C: Reinforced buildings, well built wooden structures

Type-X: Other types not covered in A,B,C. These are generally light constructions.

*Source: Vulnerability Atlas of India (1999)

The majority of houses in villages under Jabalpur urban area are of (a) mud (reinforced with straw), having 60-75 cm thick walls, (b) thick stone strips in mud/lime mortar, having wall thickness of 35 to 60 cm, (c) unburnt clay bricks in mud/lime mortar having wall thickness of 35 - 50 cm (Type-A Structures). The roofs are made of thatch of bamboo or other plants covered with earthen tiles supported on wooden purlins. The roof and cantilever projection all around the house are supported on wooden ballies/wooden columns/mud pedestals. There is no interlocking / connection between the wall and roof, making the structure more vulnerable during earthquake. The supporting columns are connected with wooden rafters by wedge kind of triangular wooden element. The various elements of trusses made-up of wooden ballies are interconnected using nails and all gable ends found without any connection/gable band.

The Existing building stock (around 70%) in Jabalpur city comprises of brick masonry in cement mortar (1:8)/ lime / surkhi / mud mortar, with 230 mm to 750 mm thick load bearing walls (Type-B Structures). These dwellings are mainly 2 to 3 story with 3.00 to 3.3 m story height. The construction practices and material used for these houses seem to vary with time. It has been found that no earthquake resistant measures have been adopted in buildings constructed before 1997 earthquake. Implementation of BIS codal provisions regarding earthquake resistant design & construction (IS: 4326-1993), were found to be absent almost in all the sample buildings surveyed, rendering the large percentage of structure seismically vulnerable. However, the post 1997 construction make use of four RCC columns of size 230 x 230 mm in corners, and RCC beams at lintel and floor level. In some of the newer construction lintels and plinth bands were found to be present.

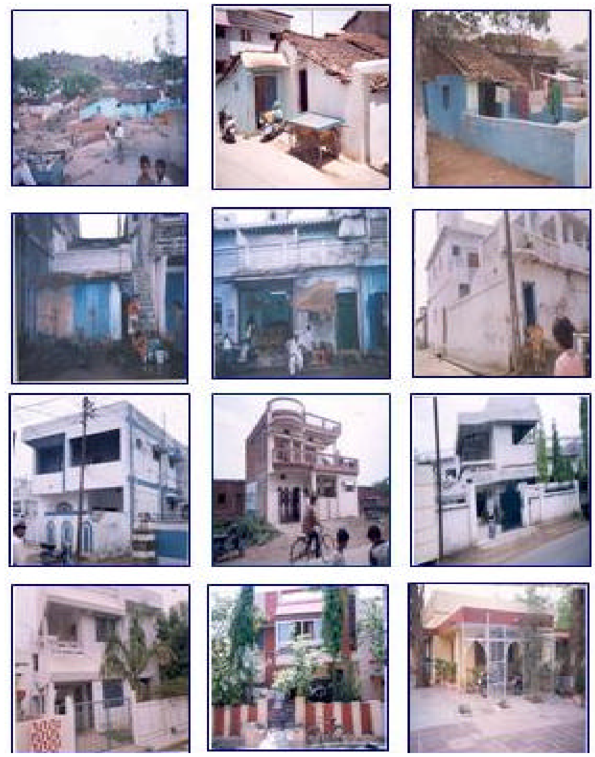

Fig. 3. Existing Building Typologies in Jabalpur Urban Area

The RC framed buildings are not much prevalent (around 15%) in Jabalpur urban area. General construction of RC framed buildings are of nominal concrete of M15 grade (1:2:4) ranging from 3 to 4 story with story height of 3.00 to 3.30 m (Type-C Structures). Among majority of RC frame buildings, around 90% buildings are soft story, with uniform cross section of columns having RCC slab of 120-140 mm thickness and 200-250 mm thick brick masonry in CM (1:6) as infill. These RC buildings are mainly designed for gravity loads without giving much attention to ductility as recommended by IS:13920-1993.

Experiences of Jabalpur Earthquake of 1997 (M6)

Jabalpur lies close to a mature zone of seismic source with recurrent seismic activity. On 22nd May 1997, the area was rocked by an earthquake of 6.0 magnitude (focal depth – 35 km) with epicentre at latitude 23.08°N and longitude 80.06°E. The Jabalpur urban domain lied in the near field of the seismic event and was in meizoseismal zone having undergone wide spread damage of intensity VIII (MSK scale). The post-earthquake reconnaissance survey during 1997 in the area carried out by different agencies viz.

GSI (Mishra, P.S. et al, 2000), CBRI (Agrawal, S.K. et al, 2002), IIT Kanpur (Jain, S.K. et al, 2001), IIT Roorkee (Rai, D.C. et al, 1997), reveal that the performance of existing building stock was poor. The obvious reason has been that earthquake resistant measures prescribed in Indian codes were not made mandatory. However, the revalidated intensity map of Jabalpur prepared by GSI, demonstrates intense accentuations and de-amplifications which could be ascribed to (a)site response characteristics and (b) variation in frequency dependent resonance of building typologies. The intensity within Jabalpur urban area domain varied from V to IX , commensurate variation in peak ground accelerations may have been from 18-22 cm/sec^2 (for intensity V) to 299 cm/sec^2 (for intensity VIII/IX; Mishra et al, 2000).

It is understandable that lack of awareness amongst the masses has been main factor in high-grade damages in Jabalpur. The fact that now in post-earthquake scenario, the seismic codes being made mandatory by local bodies will go a long way towards better earthquake safety. Moreover, the increased concern about earthquake issues amongst the decision-makers and administrators with increased earthquake awareness will contribute enormously to risk reduction.

Past Attempts for Assessment of Vulnerability

The first attempt to create Vulnerability Atlas of India (MP) – 1997 (Arya, 1997) details out housing vulnerability tables wherein damage risk levels for earthquakes are defined based on the intensity scale such as Very High, High, Moderate, Low, and Very Low, and categorization of houses has been carried out based on distribution of houses by predominant materials of roof and wall, according to 1991 Census. The statewise Vulnerability Atlas, describing districtwise damage risk due to earthquake, wind and flood has been prepared Accordingly, the earthquake damage risk associated for Jabalpur urban area varies from very low, low, & medium to Type-C, Type-B, & Type-A houses respectively. However, May 1997 Jabalpur earthquake caused severe damages leading to collapse of Type-A and Type-B houses, in particular, based on various damage survey reports. There has not been any other reported literature on seismic vulnerability of existing building stocks of Jabalpur urban area, which is one of the important modules for any microzonation study. The paper aims to have a deeper look for assessing seismic vulnerability of different types of structures based upon latest international & national practices on seismic evaluation.

Seismic Evaluation: Methodology

Indian buildings built over past two decades are seismically deficient because of lack of awareness regarding seismic behavior of structures. Also seismic design is not practiced in most of the buildings being built. It calls for seismic evaluation of existing building stocks in an area.

Evaluation is a complex process, which has to consider not only the design of building but also the deterioration of the material and damage caused to the building, if any. The difficulties faced in the seismic evaluation of a building are manifold. There is no reliable information/database available for existing building stock, construction practices, in-situ strength of material and components of the building. The seismic evaluation mainly relies on set of general evaluation statements, since analytical methods to model the behavior of buildings during earthquake defining response spectra of structure are too complex to handle with the generally available tools and calls for rigorous engineering seismological exercise. The non-availability of a reliable estimate of earthquake parameters, to which the building is expected to be subjected during its residual life poses another challenge. Probabilistic approach to evolve needful parameters, would call for elaborate studies. Hence, for preliminary appraisal, the ground motion parameters available in the present code (IS:1893-2002) have been estimated at the macro level. As regards the effect of local soil conditions, which are known to greatly modify the earthquake ground motion, experiences of ground accentuation and data generated through collateral studies on site response have been considered. Also, in view of above constraints, the present study is limited to seismic evaluation of representative buildings of different typology viz. Type-A (Mud/RR Masonry, Adobe), Type-B (Brick Masonry Buildings), and Type-C (RCC Buildings), and projects a generalized pattern of building response to future seismic ground motion in different wards of Jabalpur urban area.

The seismic evaluation leading to seismic vulnerability of existing building stock at Jabalpur has been estimated quantitatively and qualitatively. The quantitative approach, covers demand-capacity computation (ATC-40, 1996), while qualitative procedure estimates structural scores based on national & international state-of-the-art procedures viz. Rapid Screening Procedure (ATC-21, 1988, ATC-21-1,1988). The general procedures for seismic evaluation of existing buildings adopted in the present study are: site visit & data collection; selection & review of evaluation statements; follow-up fieldwork; and analysis of buildings by quantitative and qualitative approach.

Designing of Questionnaire

Designing of questionnaire comprising of set of evaluation statements is the first and foremost step for any seismic vulnerability analysis. The questionnaire would help the surveyor to determine any weak links in the structure that could precipitate structural or component failure. Although for macroseismic/post-earthquake damage investigations several questionnaires (Gunthal, 1993) are devised, however, for pre-earthquake seismic evaluation of existing building stocks there is no standard questionnaire at international & national levels. Hence, a need was felt to design exhaustive questionnaire to uncover the flaws and weaknesses of buildings/built environment. In the backdrop of available practices being adopted all over the globe, a comprehensive questionnaire has been designed. The questionnaire involves the use of sets of evaluation statements which cover structural configuration & specification, condition of structure & ambience, scenario of distress in non-structural components, seismic vulnerability parameters, damage during previous earthquake and repairs carried out thereof, and assessment of scientist/surveyor. The questions are in form of fill-in-the-blanks and positive evaluation statements highlighting building characteristics which are essential to avoid failures during earthquake.

Site Visit & Building Survey

Administrative Units of Jabalpur Urban Area. In order to evaluate seismic vulnerability of huge number of building stocks in Jabalpur urban area, it is practically impossible to survey each and every house; hence it was considered appropriate to divide Jabalpur urban area into number of small zones based upon structural/population density. The Jabalpur urban area is divided into 60 numbers of municipal wards as delineated by Jabalpur Nagar Nigam (Municipal Corporation of Jabalpur). These 60 wards are taken as zone in the present analysis. In addition, Jabalpur Cantonment Area and surrounding villages have been considered as a separate zone. Detailed reconnaissance survey of existing buildings stocks of each ward has been conducted. Based upon the observations, 3-4 representative building samples of different building typologies are selected for detailed investigation from each ward.

Selection of Building Samples. During the detailed survey, buildings of each type (i.e. Type-A, Type-B, and Type-C) have been identified, with the assumption that selected building represents construction practices being prevalent in that particular ward/zone. This was done with the mutual consensus amongst the team members and Corporator of the ward. Wherever the construction practices varied drastically in a ward, more number of samples were identified so as to cover each type of construction in a ward. The sample survey was done with the aim that the seismic vulnerability analysis to be carried out, on those sample buildings would represent seismic vulnerability of each type of building in that zone.

Detailed Survey of Selected Buildings. Apart from filling-up of questionnaire for the selected buildings, surveyor has to inspect the health of structure critically to assess its seismic resistance. In the process, surveyor has to face several difficulties. The foremost problem is of uncovering the structure. In many buildings the structure is concealed by architectural finishes, and the surveyor had to get into attics, crawl spaces. Non-availability of plans, and design calculations is yet another problem, and is particularly frustrating with respect to reinforced concrete work. Assessing material quality and associated allowable stresses is also difficult preposition , and one has to rely on local available reports/information or otherwise one has to go for destructive testing, which is seldom possible. Destructive and non-destructive testing of reinforced concrete and masonry elements are necessary to determine strength and quality of construction. The rebound hammer is used to assess the compressive strength of structural members, wherever access is provided in reinforced concrete structure. If reinforcement details are available, a limited amount of exposure of critical reinforcement are needed to verify conformity to the plans/structural details. If the plans are not available, the quality of reinforcement is assessed by exposing reinforcement to a limited extent.

The sample survey was carried out for about 474 buildings spread over 62 zones of Jabalpur urban area including 22 surrounding villages, out of which 33% are of Type A, 52% are of Type B and 15% are of Type C**.**

Seismic Vulnerability Analysis

The seismic vulnerability of all types of buildings have been assessed by two different approaches. For qualitative assessment of buildings, Rapid Screening Procedure has been used to assess vulnerability of all types of structures, while for quantitative approach, DCR computation has been used for Type B & C buildings and later it is related with the possible failure modes.

Quantitative Seismic Vulnerability for Masonry Buildings

Since earthquake is a random process, all the load bearing walls in a structure are to be evaluated for their shear resistance. The demand placed by an earthquake i.e. lateral forces at various levels, as per IS:1893-2002, along with gravity load calculations were carried out for sample buildings, and later check in terms of Demand –Capacity ratio (DCR) for shear resistance, combined stress, overturning, and stability of non-structural failures for long and short walls performed for Type-B buildings. The capacity of wall is defined as its allowable stress depending upon mortar type in accordance with the relevant codal provisions. The DCR greater than unity, indicates that the building is seismically vulnerable in respective criterion, whereas DCR less than one implies the building to be safe under earthquake loads. As indicated earlier, earthquake demands for better shear resistance and hence the DCR in shear should be less than one, otherwise the building will have diagonal (X) cracking. The DCR greater than one for combined stresses means that the building is not even designed for gravity loads and would lead to collapse on seismic shaking. The failures in overturning corroborates falling of walls. The check for non-structural element implies the falling hazard of parapet wall. The above analogy has been used to estimate seismic vulnerability i.e. collapse, excessive cracking, falling of walls including parapet walls.

Quantitative Seismic Vulnerability for RC Buildings

In order to critically evaluate the RC framed buildings, selected building sample were modeled using sophisticated structural analysis software under combination of loading for computing the end forces in each structural member. Apart from the dead & live loads, building has been evaluated to the design basis earthquake (DBE) loads, the earthquake loads which can reasonably be expected to occur at least once during the lifetime of the structure. Accordingly, dead load, live load and their combination thereof as suggested in IS-1893-2002 have been considered for analysis. The analysis directly computes member end forces and then each member is designed for worst load combination. The design module of analysis engine gives the longitudinal and transverse reinforcement for each member. This reinforcement corresponds to the demand of a member due to earthquake forces, whereas the actual reinforcement provided in a particular member would correspond to capacity. In order to calculate the DCRs, the calculated reinforcement of structural members has been compared with provided reinforcement. The DCRs for longitudinal and transverse reinforcement reflects DCRs for flexure and shear of member. The DCRs calculated for flexure and shear gives the idea about inherent ductility and strength of member to ensure safety & serviceability during severe shocks.

The DCR greater than one for flexure indicates that the longitudinal reinforcement in columns & beams are inadequate leading to failure. The possibility of failure of such buildings is excessive cracking leading to collapse. Whereas DCR greater than one in shear indicates that the lateral ties provided are not sufficient leading to brittle failures i.e. catastrophic failure. In this case, there is possibility of diagonal cracking in structural elements. The check for non-structural element implies the falling hazard of parapet wall. Based upon above analogy, DCRs for flexure, shear and non-structural members leading to estimate seismic vulnerability i.e. excessive cracking, diagonal cracking and falling hazard respectively, for all the representative RC buildings under consideration have been computed.

Qualitative Seismic Evaluation for Buildings

The Rapid Screening Procedure (RSP) is aimed to identify potentially hazardous buildings in the study area, without going into detailed analysis. RSP utilizes a methodology based on visual inspection of a building and noting the structural configuration. The methodology begins with identification of the primary structural lateral load resisting system and materials of the building. The method generates a Structural Score 'S', which consists of a series of 'scores' and modifiers based on building attributes that can be seen during detailed survey. The Structural Score 'S' is related to probability of the building sustaining life-threatening damage in the event of occurrence of a severe earthquake in the region. A low S score suggests that the building is vulnerable and needs detailed analysis, whereas a high 'S' score indicates that the building is probably adequate. RSP helps in developing a list of potentially hazardous buildings without a high cost of detailed analysis of each building. In the present study, this method has been used for qualitative assessment of seismic vulnerability of existing buildings in Jabalpur urban area.

Based upon the survey and evaluation statements, the final structural score (S) has been computed for individual selected buildings to assess their seismic vulnerability.

Prognostic Damage Scenario of Jabalpur Urban Area

The prognostic damage scenario of a ward reflects the structural and non-structural damages induced in the existing building stocks. The damage scenario of a ward given here is based on representative building surveyed for different building typologies.

Based on the survey & analysis of data, the seismic vulnerability of Jabalpur urban area obtained through qualitative approach, Type-A, Type-B & Type-C buildings are 100%, 87%, & 33% vulnerable respectively.

In order to present the prognostic damage scenario for Jabalpur urban area using quantitative approach, the failures modes of different type of buildings are collated, and indicates that all the Type-A houses are 100% vulnerable since they are built from socio-economic consideration rather than engineering. In order to carry out prognostic damage scenario of Type-B buildings, the postulated failure modes have been categorized as excessive cracking (EC); falling of walls (FW); falling hazard of non-structural members (FH); and combination thereof - Excessive cracking + falling of wall (EC+FW); excessive cracking + falling hazard (EC+FH); falling of wall + falling hazard (FW + FH); excessive cracking + falling of wall + falling hazard (EC + FW + FH); and safe buildings (which do not have any failure). At the first instance, wardwise seismic vulnerability has been derived, and later the ensemble is projected to present prognostic damage scenario for Jabalpur urban area. *The prognostic damage scenario for Jabalpur urban area for Type-B structures obtained as "Excessive Cracking (EC)* works out to *15%; Falling of Walls (FW) – 0%;* ***Falling Hazard of non-structural members (FH) – 29%****; and combination thereof - Excessive Cracking + Falling of Wall (EC+FW) – 2%;* ***Excessive Cracking + Falling Hazard (EC+FH) – 36%****; Falling of Wall + Falling Hazard (FW + FH) – 1%; Excessive Cracking + Falling of Wall + Falling Hazard (EC + FW + FH) – 1%; and* ***Safe buildings – 16%*** *(Fig. 4).*

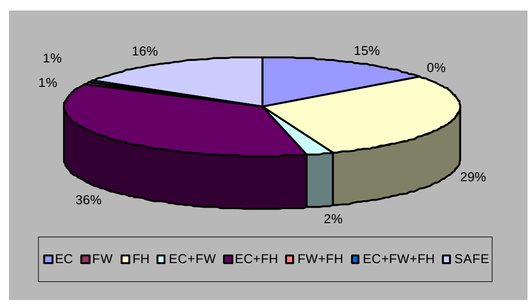

Fig. 4. Prognostic Damage Scenario of Type-B Buildings in Jabalpur Urban Area

Similarly, the various failures modes for assessing seismic vulnerability of Type-C buildings are identified as excessive cracking (EC), diagonal cracking (DC); falling hazard of non-structural members (FH); and combination thereof and safe buildings. The prognostic damage scenario for Type-C buildings in Jabalpur urban area obtained as "*Excessive Cracking (EC) – 0%; Diagonal Cracking (DC) – 0%; Falling Hazard (FH) – 34%;* ***Excessive & Diagonal Cracking (EC+DC) – 9%***; ***Diagonal Cracking + Falling Hazard (DC+FH) – 7%***; ***Excessive Cracking + Falling Hazard (EC+FH) – 7%;*** ***Excessive Cracking + Diagonal Cracking + Falling Hazard (EC + DC + FH) – 32%***; and ***safe buildings – 11%***. *The overall prognostic damage* *scenario of Jabalpur urban area for this kind of buildings is presented in Fig. 5. The falling hazards are essentially non-structural failures and therefore these buildings may also be deemed to be safe after minor modification to non-structural elements making around 45% safe RC structure.*

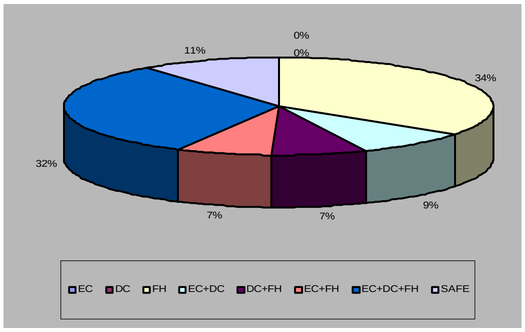

Fig. 5. Prognostic Damage Scenario of Type-C Buildings in Jabalpur Urban Area

Figure 6 presents Prognostic Seismic Vulnerability Map of Masonry Buildings in Jabalpur. The vulnerability map can be effectively used to project the risk associated with existing building stock in Jabalpur Urban area. Further, these maps may act as guidance for future planning, risk reduction and disaster mitigation and management.

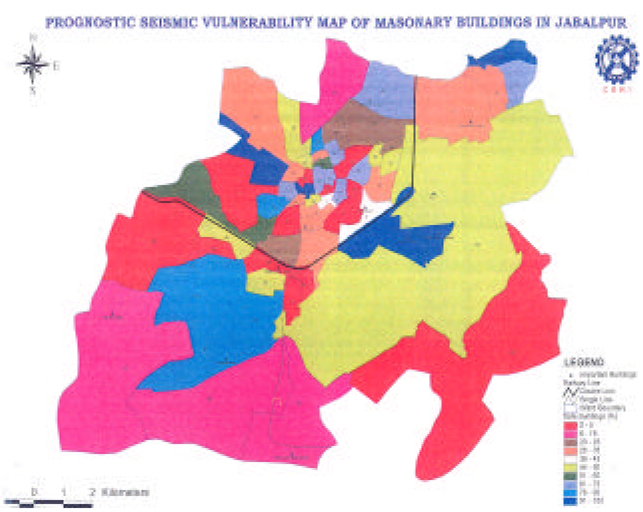

Fig. 6.: Prognostic Seismic Vulnerability of Masonry buildings in Jabalpur Urban Area

DEHRADUN

Located in the foothills of Himalayas, Doon valley is in the process of gradual differential uplift. A number of faults and lineaments have been identified and extensively mapped. The Doon valley, which is confined between the Main Boundary Thrust on its north, the Himalayan Frontal Thrust on its south, and rivers Yamuna and Ganga on its eastern and western sides, is a tectonically isolated block. CBRI undertook a study on Seismic Microzonation and Predicting Damage Scenario of Dehradun City. The main objective of the study is to evolve suitable methodology for predicting seismic damage scenario of the vulnerable city and to prepare damage scenario maps for selected parts of the city using GIS techniques.

The city located in the Doon Valley in Himalayas, has recently become the capital city of newly formed Uttaranchal State. The Latitude and Longitude of Dehradun are approximately 30^0 N and 78^0 E respectively. The city has the population of around 1.2 million having urbanized area of approximately 140 sq. km. Around 1,50,000 housing units exist in the city. The expected PGA value for the Doon Valley region is 0.7g with 10% probability in 50 years. Dehradun lies in the seismic intensity zone IV (Zone Factor Z=0.24) and its surroundings in zone V (Z=0.36) according to the Indian seismic code.

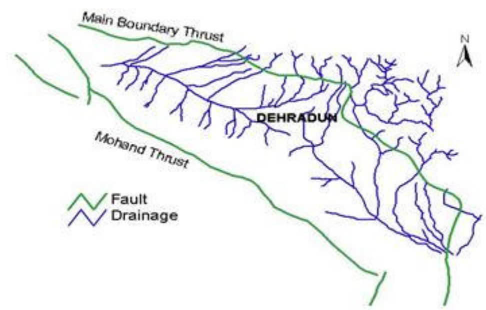

Fig 7. Fault and Drainage Map of Doon Valley

<u>Details of Study</u>

This project is first of it's kind in India and a suitable building inventory format is being designed from earthquake resistance point of view. An Inventory has been prepared which is suitably designed for quick assessment of seismic performance of the building. The building inventory is of two types i.e. for masonry load bearing structures and RCC framed structures. The inventory provides the general information about the building & the technical information about the parameters, which directly affect the performance of a building during earthquake. A deep thought has been given to these parameters and proper weightages have been assigned to them. Parameters considered are number of stories, shape of building, opening in walls, type of construction, quality of construction, earthquake resistant provisions, wall density, foundation etc.

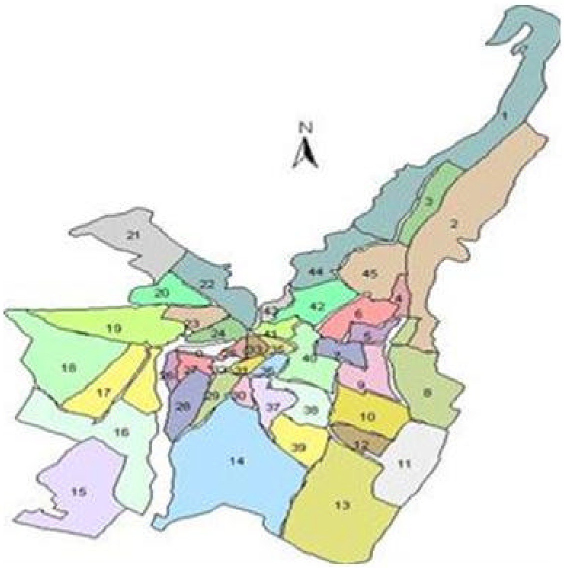

Fig 8. Block Map of Dehradun City

The team of scientists of CBRI, Roorkee carried out sample survey of some 'Governmental' as well as 'Private' buildings in the blocks shown in Fig 8.

Nearly 1500 buildings (roughly 1% of total existing) have been surveyed by a team from the Institute. Survey reveals that approximately 94% of buildings consist of masonry and the rest falls in RCC framed construction. The building inventories have been filled at the site itself by the project team. Bore hole data samples have also been collected for the valley. Micro-tremor data were also collected at five pockets with the help of visiting Japanese experts. Analysis for the collected data is in progress and damage scenario for the complete city will be predicted soon.

CONCLUSIONS

The following preliminary conclusions are drawn from Delhi microzonation study based on the data collected for real earthquakes, ambient noise analysis & site response studies.

- Hard rock sites do not show any clear-cut peaks of H/V ratio.
- Sites with thick soil cover show amplification of horizontal motion by vertical motion (H/V ratio) at frequencies between 0.8 Hz to 3 Hz. One typical example is Jasola near Yamuna river where amplification level is 6.2 at frequency of 3 Hz.
- The ridge is a very stable site where no records could be obtained even during peak traffic hours with minimum threshold value. However, the site INSDOC near IIT Delhi having thin alluvial cover shows amplification of 2.4.
- Movement eastward and westward from the ridge clearly indicates change is frequency level.
- The natural frequencies of the ground clearly show their dependence on the soil cover thickness

Based on qualitative and quantitative analysis of the data collected during the survey and its analysis & interpretation, the following conclusions for predicting seismic damage scenario for Jabalpur are drawn.

The buildings in field-stone, rural structures, unburnt brick house, clay houses ***(classified as Type-A)****, comprises of* ***15% of total building stock*** *in Jabalpur urban area. All the buildings lack seismic resistant measures and are* ***likely to fail*** *in the event of an earthquake.*

The majority of building stock ***(70%)*** *is composed of* ***Type-B buildings*** *which include ordinary brick buildings, buildings of the large block, half-timbered structures, buildings in natural hewn stone. Around* ***16% buildings are safe****, while 84% buildings are likely to suffer damages in form of excessive cracking, falling of walls, falling hazard of non-structural component and combination thereof.*

The engineered RC construction typically consists of RC Moment Resisting Frames ***(Type-C)*** *which constitutes about* ***15% of total building stock****. In case of an earthquake around* ***45% buildings are safe*** *whereas rest of Type-C buildings are likely to suffer damages in the form of excessive cracking, diagonal cracking, falling hazard and its combination.*

The study presents the seismic damage scenario of Jabalpur urban area taking into account all prevalent construction practices. However, the study is based on a limited sample size of 474 representative building from different microzones.

The present study on vulnerability when integrated for damage scenario analysis on incidence of earthquake with collateral geoscientific studies corroborates the finding of revalidated intensity map of Jabalpur Earthquake 1997.

The studies for Dehradun are currently underway & are not conclusive. These risk microzonation studies demands special attention with reference to heritage/monumental buildings, lifelines like rail/road, water supply, electric supply, sewage, communication, dams, hospitals & schools, vulnerable industries, which is missing in the present study. Also there is a need to identify safe zones/domains/structures and secure routes to work as a relief centers and relief dispersion on incidence of future disaster.

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